

## **- Detecting High Energy Radiation -**

**NOAJ Astrophysics Lecture Series, November 2013**

**Introduction to Observational Nuclear Astrophysics  
Lecture #4**

**by Roland Diehl**

# Focussing at Smaller Wavelengths

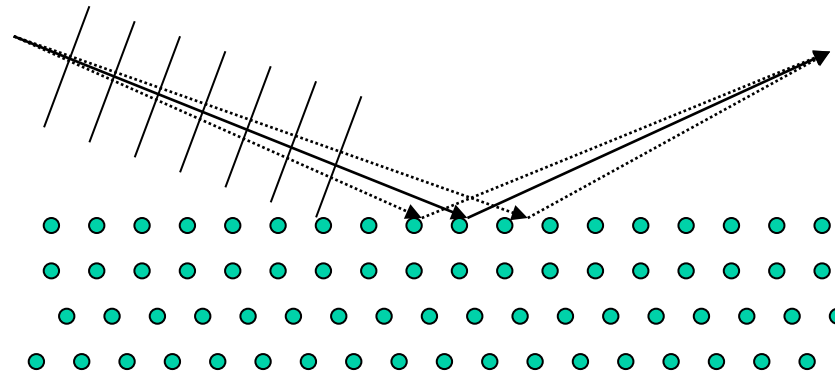
☆ Below  $\sim 1000 \text{ \AA}$ , Reflection gets more **scattering** than **specular**

☆ **Physical reason:**

When  $\lambda$  is of the order of the structure of the "surface" of a mirror:

→ No cancellations of "indirect" paths of the e.m. wave functions

(in QED picture)



☆ **"Trick" at X-ray Energies:** **Grazing Incidence**

👉 This shifts the problem to somewhat higher energies ( $\sim 100 \text{ keV}$ )

# Non-focusing X-ray telescopes

## Two Elements (Detector, Shield-Detector)

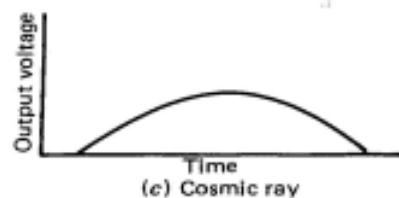
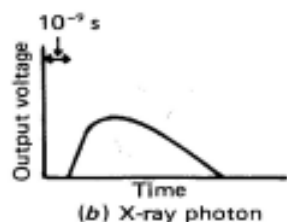
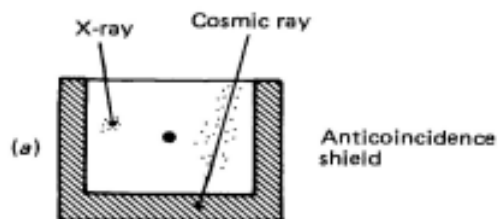
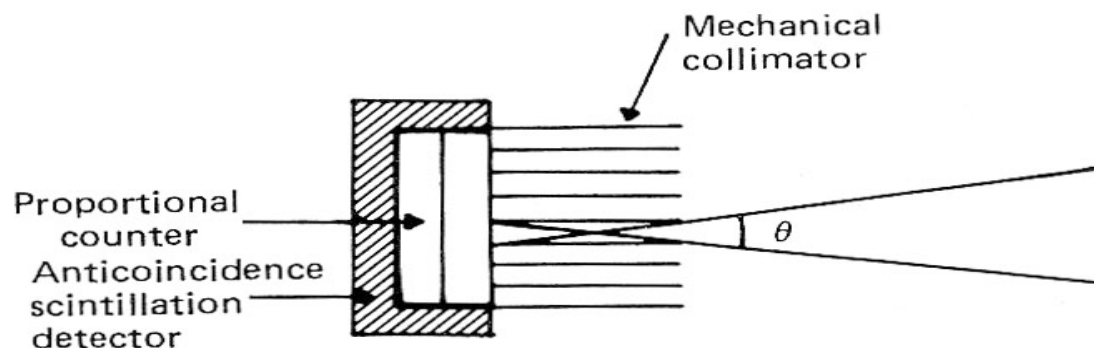


Figure 7.8. Diagrams illustrating the principles of rise-time or pulse-shape discrimination between X-rays and cosmic rays.

- shield works as a second “detector”
  - CR's: signal in both devices
  - X-rays: signal only in detector
- 'phoswich': two different detector elements, single readout of pulse shape
  - ➔ Distinction X/CR possible

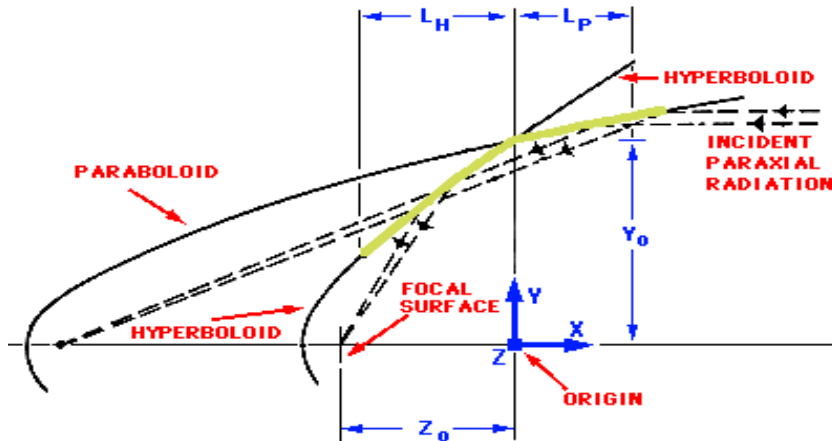


## Collimators

- to avoid light from unwanted directions
- implemented with metallic tubes

# Wolter type I telescopes (I)

## Paraboloid and Hyperboloid, combined



- minimal focal length  $F$   
for a given aperture  $Y_0$  with

$$F = Y_0 / \tan(4\theta)$$

$Y_0$  = aperture radius

$\theta$  = on-axis incidence angle

- geometric area (per shell) rather small because
  - just one ring
  - central X-rays won't be reflected  $\Rightarrow$  loss



$$S_v = \frac{\pi \phi_2^2}{4}$$



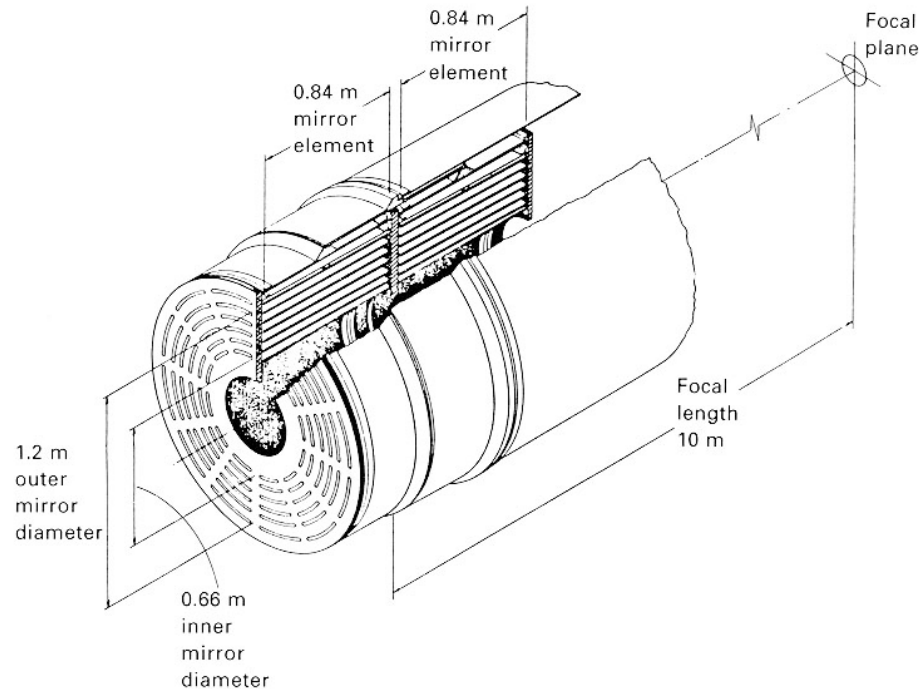
$$S_1 = \frac{\pi (\phi_2 - \phi_1)^2}{4}$$



$$S_x = \frac{\pi (\phi_2 - \phi_1)^2}{4}$$



# Example: The Chandra Mirrors



- full thick shell mirrors – coating with Ir
- extremely high angular resolution of  $1.5''$
- shell's thickness:  $\sim 2 - 3$  cm
- made of Zerodur  
(= glass with an expansion coefficient = 0)

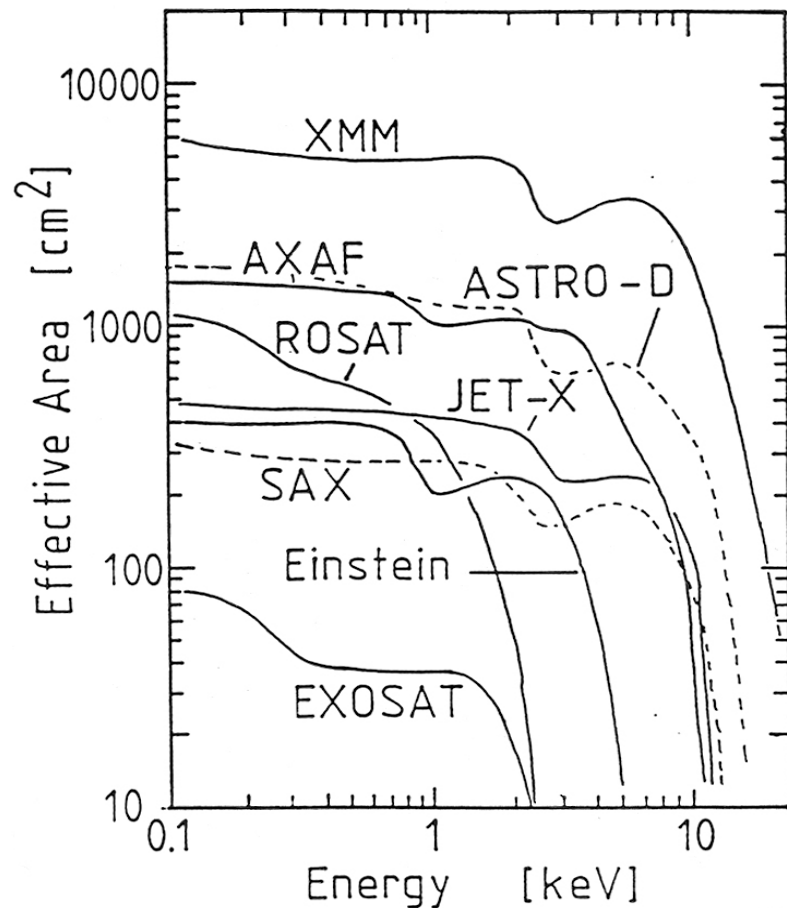


# X-ray Telescope Mirrors

- Parameters and performance:

|                                   | X-ray Telescope Mirrors |          |          |            |          |           |
|-----------------------------------|-------------------------|----------|----------|------------|----------|-----------|
|                                   | Einstein                | EXOSAT   | ROSAT    | BBXRT/ASCA | Chandra  | XMM       |
| <i>Mirror Characteristic</i>      |                         |          |          |            |          |           |
| aperture diameter                 | 58 cm                   | 28 cm    | 83 cm    | 40 cm      | 1.2 m    | 70 cm     |
| mirrors                           | 4 nested                | 2 nested | 4 nested | 118 nested | 4 nested | 58 nested |
| geometric area (cm <sup>2</sup> ) | 350                     | 80       | 1140     | 1400       | 1100     | 6000      |
| grazing angle (arcmin)            | 40-70                   | 90-110   | 83-135   | 21-45      | 27-51    | 18-40     |
| focal length (m)                  | 3.45                    | 1.09     | 2.4      | 3.8        | 10       | 7.5       |
| mirror coating                    | Ni                      | Au       | Au       | Au         | Ir       | Au        |
| highest energy focused (keV)      | 5                       | 2        | 2        | 12         | 10       | 10        |
| on axis resolution (arcsec)       | 4                       | 18       | 4        | 75         | 0.5      | 20        |

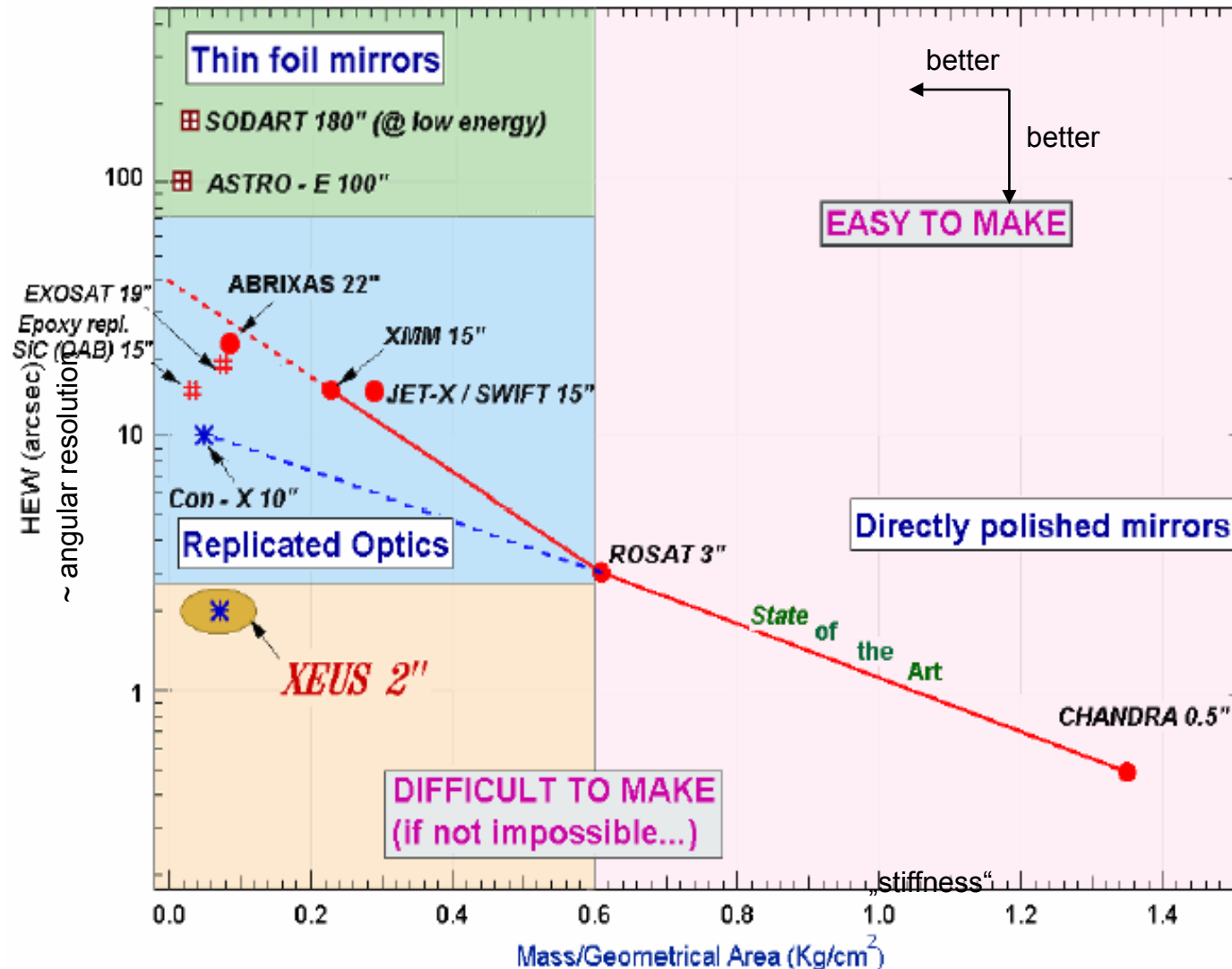
# Effective Area of X-Ray Mirrors



Comparison of effective areas of various X-ray mirrors

- effective Area  
= total geometric Area \* reflectance
- XMM-Newton: 5 \* Chandra
- ~ 2.2 keV:  
gold edge (of reflectivity) clearly visible
- ~ 10 keV:  
much longer focal lengths needed

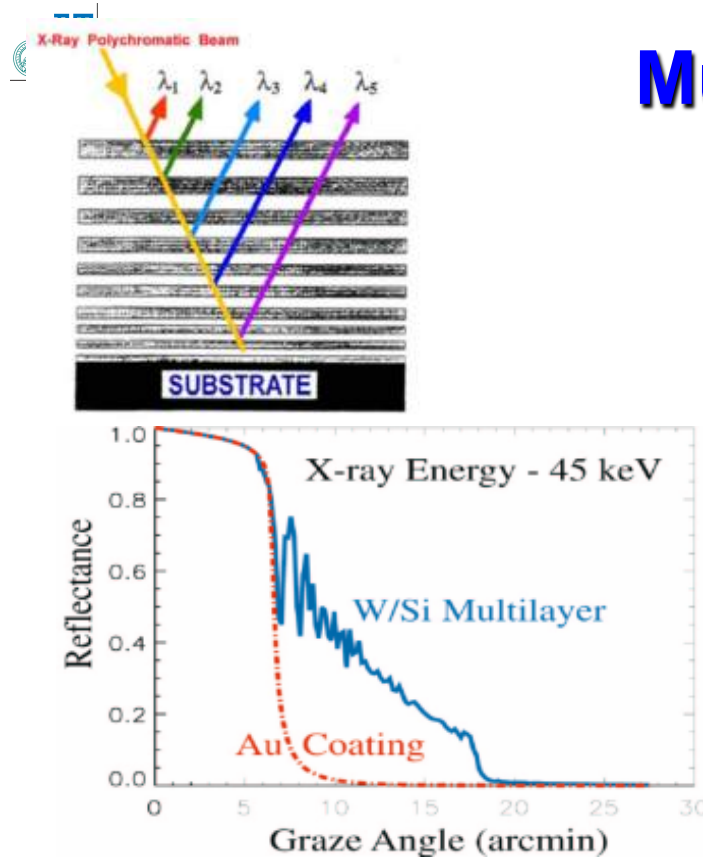
# X-ray mirror performance



- It is difficult to produce high-quality mirrors
- to reach higher resolutions:  
large increase in the mass/geom.-area ratio necessary



# Multilayer Mirrors

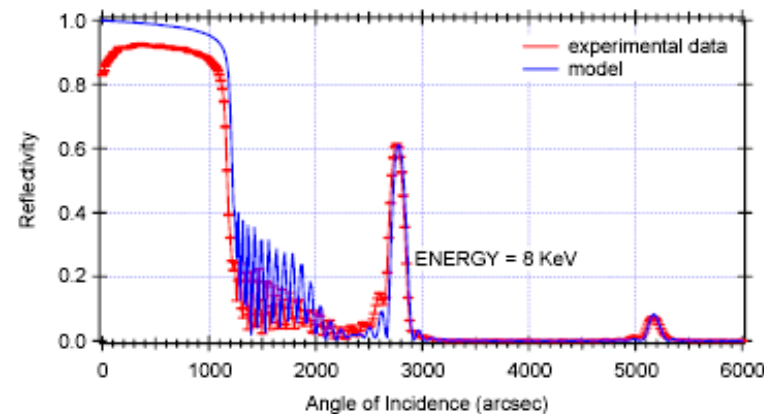
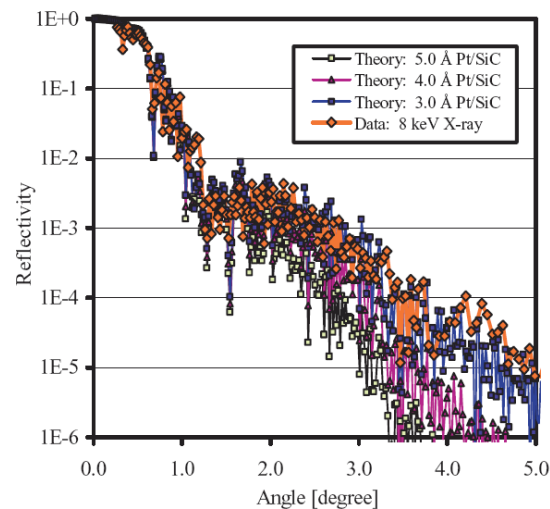


- Stack of alternating layers  
(materials of low and high Z + index of refraction)

- operating on the basis of Bragg reflection

$$n\lambda = 2d \sin \theta \quad d = \text{bi-layer thickness}$$

- wide range of thicknesses  
    ➔ broad-band reflectivity
- limit: W line edge at 70 keV





- An X-Ray Telescope extended towards  $^{44}\text{Ti}$  Lines (80 keV)

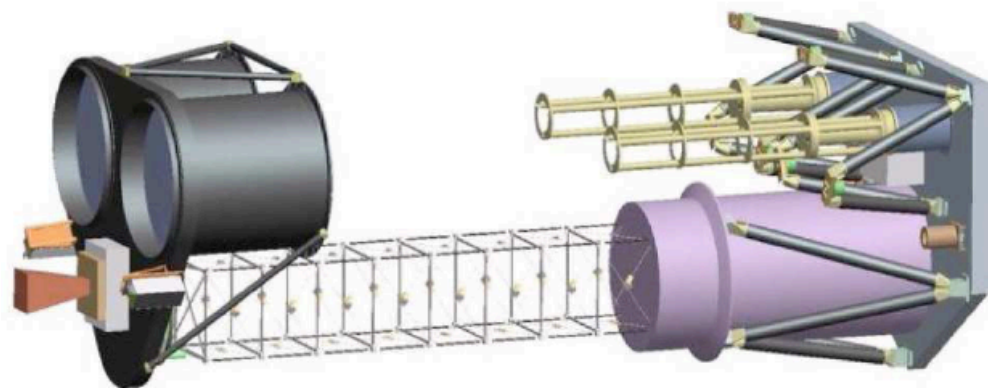
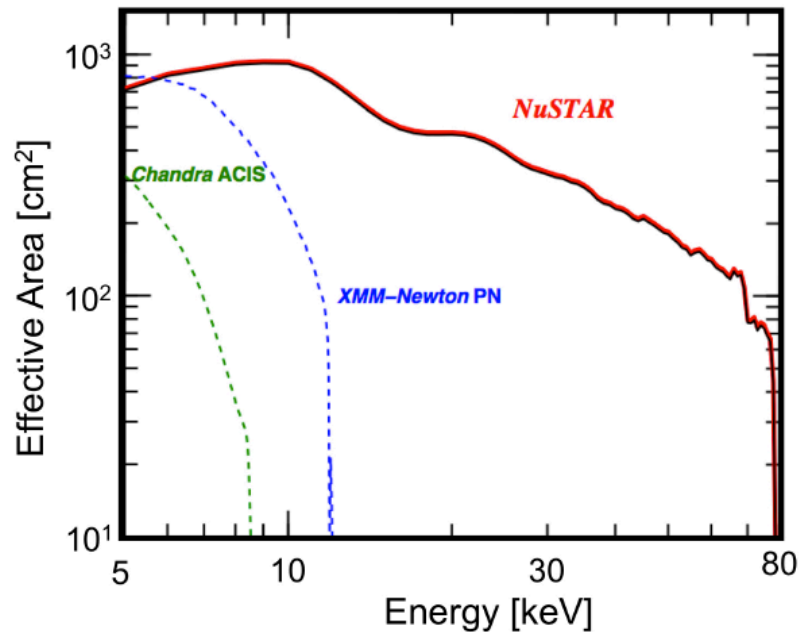
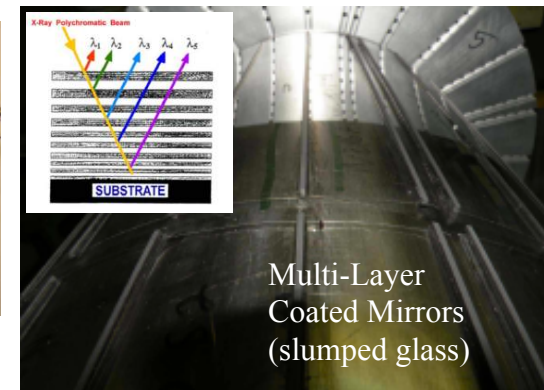
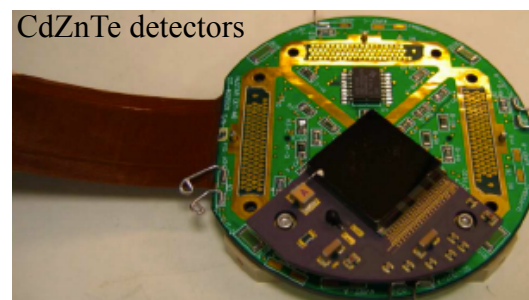


Fig. 1. NuSTAR telescopes in deployed configuration

**Launch  
in June 2012**  
(Pegasus Rocket from Airplane)



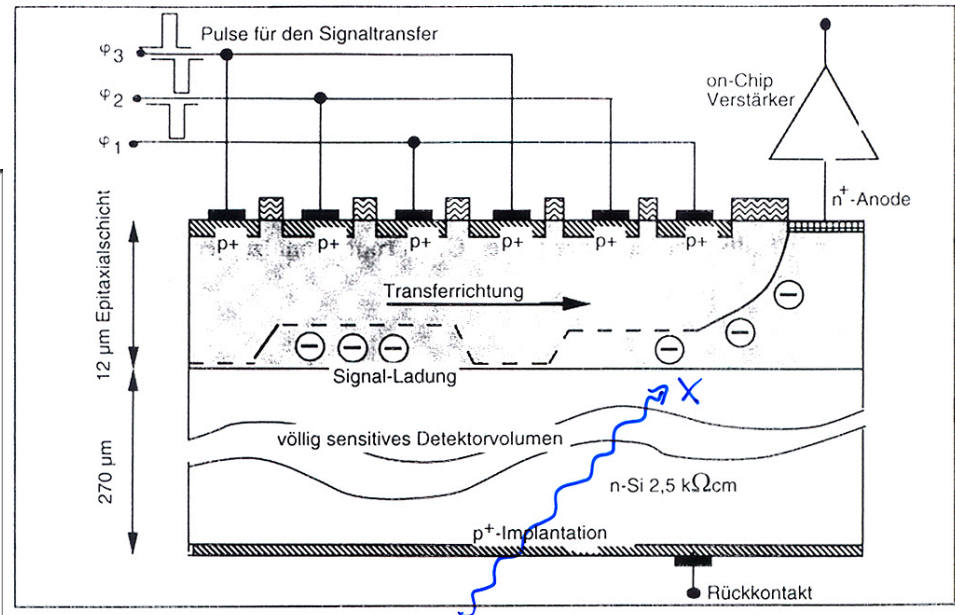
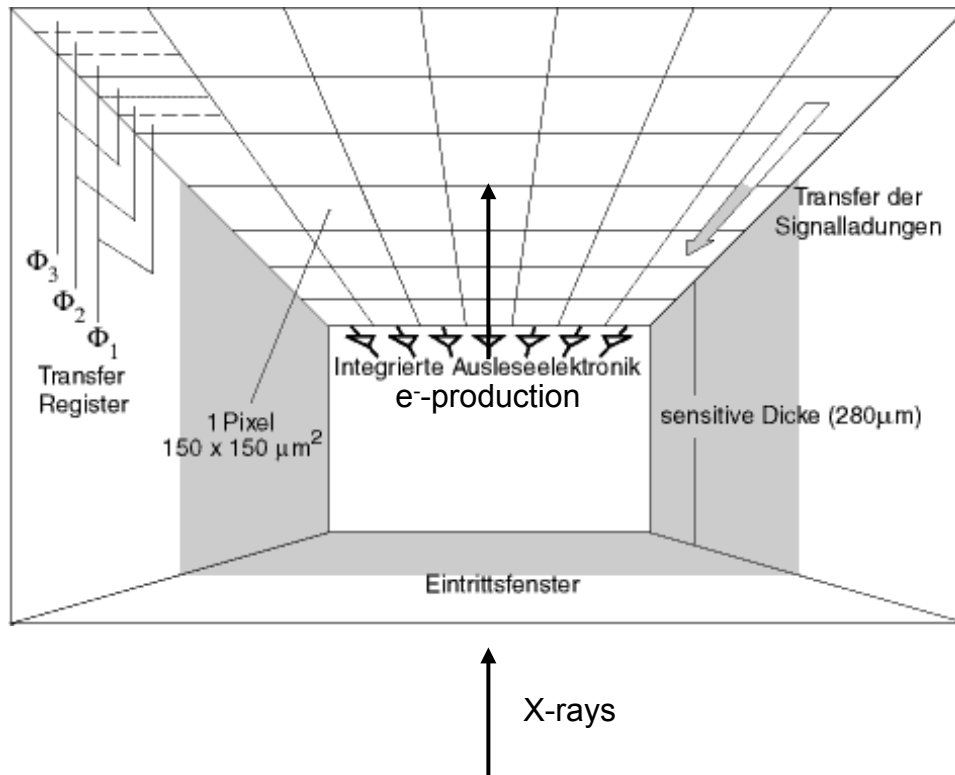
# X-ray Detector Types

- Scintillation detectors
- Geiger-Müller-counter
- Proportional counters / gas detectors
- Microchannel plate detectors (MCP)
- Charge-Coupled Devices (CCD)
- Spectroscopic devices: gratings
- X-ray bolometers / calorimeters

# pn-CCD Operating Principle



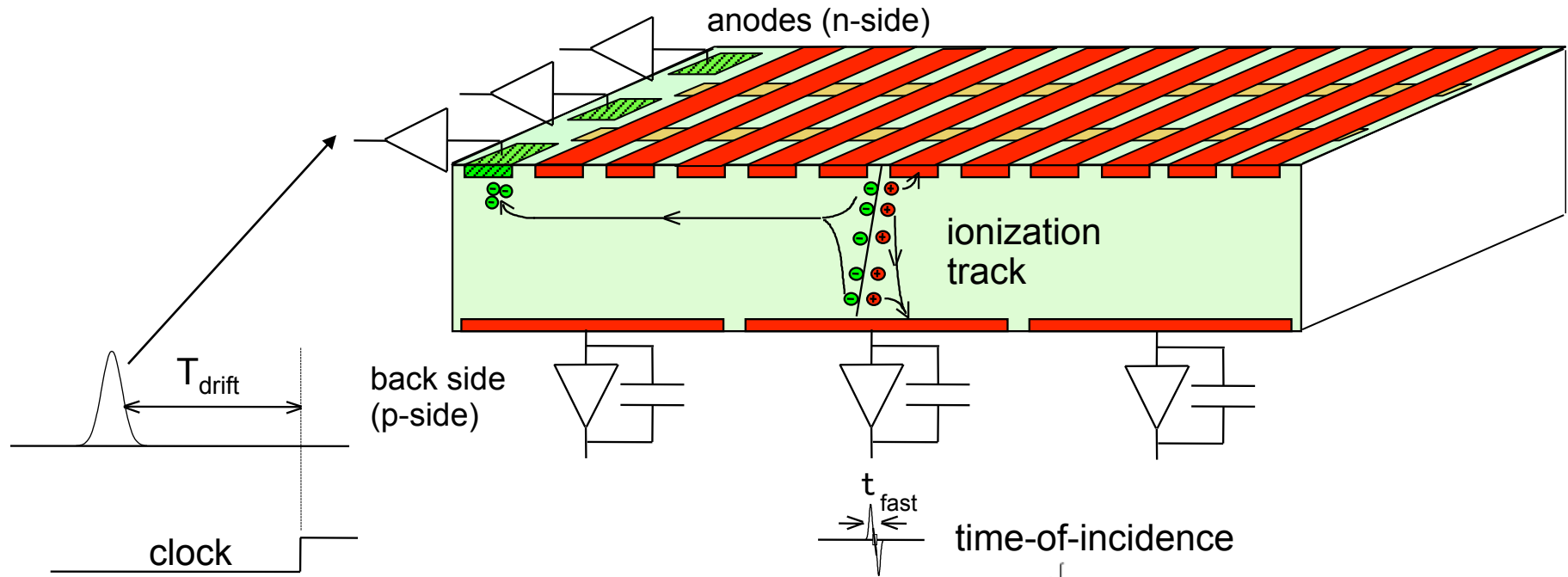
view from inside the CCD, from the n-side



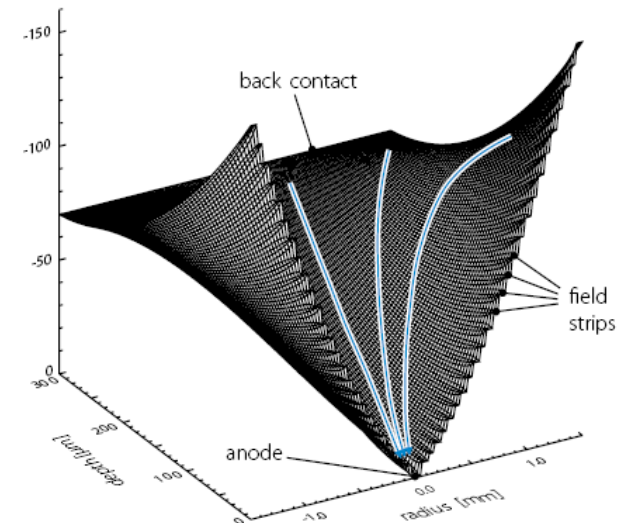
- applying an electric field in the Si sensitive region
- transfer of the created charges to the gate
- cycling the voltages of the electrodes
  - ➡ move of the charges to the read-out



# Si Drift Detectors



- Analogue signal from collection of charges
- Fast trigger from electron-hole induction on back electrodes
- Achievable time jitter depends on induction signals, electronic noise, etc..



# X-ray Spectroscopy



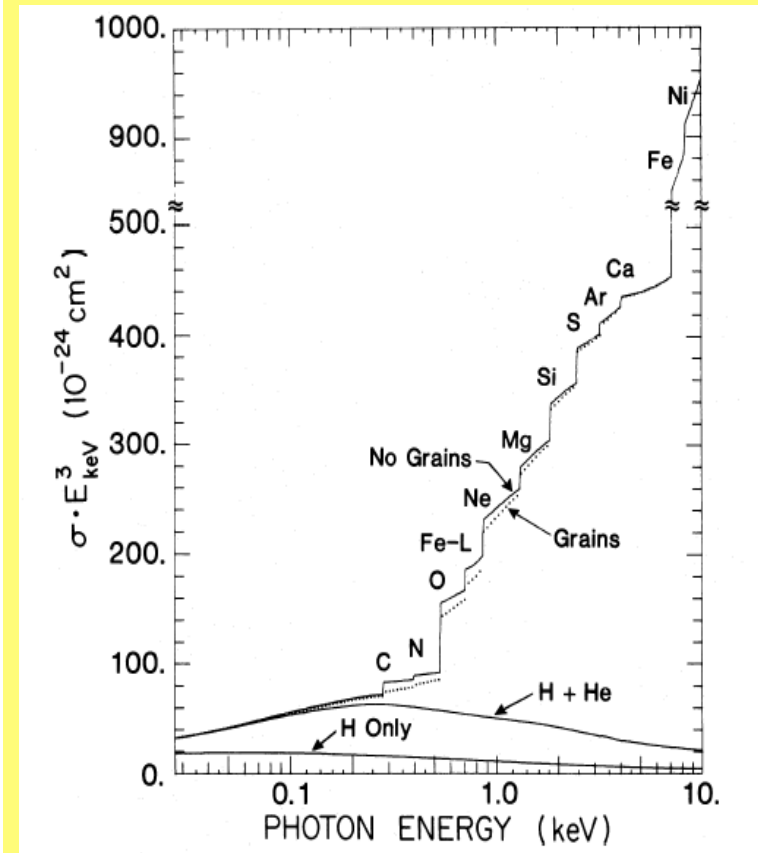
## ☆ At X-ray Energies:

☞ **Characteristic "Edges" in Spectral Distribution**

☞ **Successive Inner Atomic-Electron Levels**

- K Shell Wavelengths  $>10\text{\AA}$  ( $<\sim 1\text{ keV}$ ) (C,N,O)

## ISM absorption



*Morrison & MacCammon ApJ 1983*

# Why High-Resolution Spectroscopy?

High-resolution spectroscopy should resolve lines that may be used to study:

-- the environmental gas conditions ( $T, \rho$ )

comparing lines from the same ion

-- the ionization balance

lines from different ions of the same element

-- the chemical abundances

lines from different elements

-- the radial velocity and red-shift

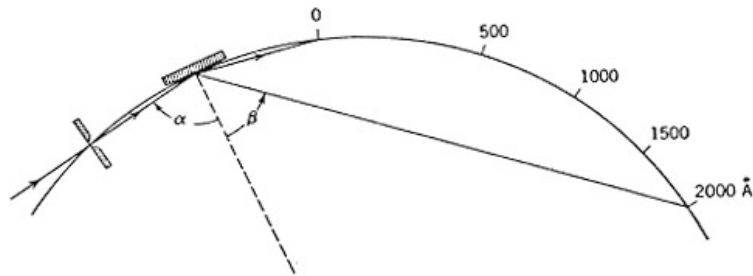
lines shifted from reference standards

-- the magnetic field (cyclotron lines)

lines at regular spacings & characteristic energies

Each astrophysical objective requires its characteristic resolving power,  $R = E/\Delta E$

# Grating Spectroscopy

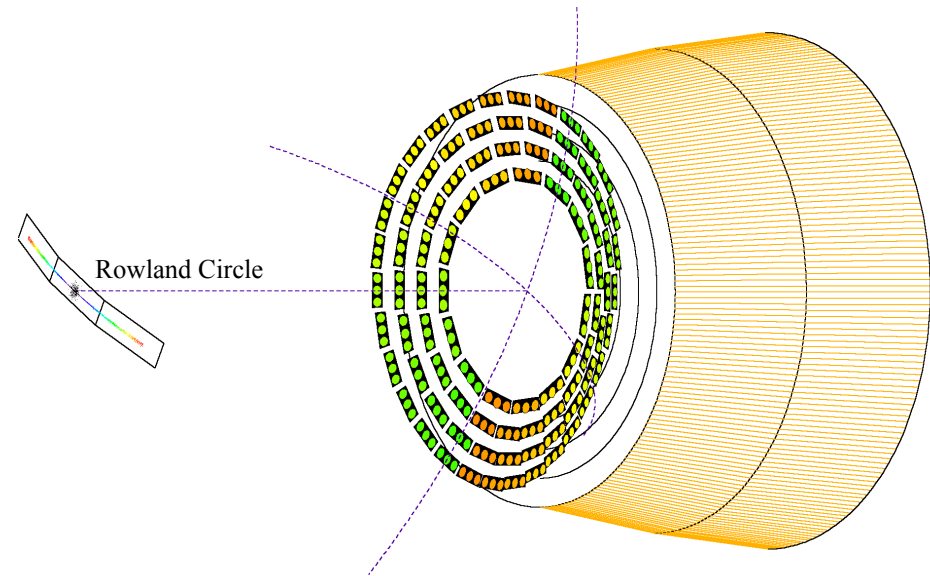


Grazing incidence spectrograph.

+ (Adapted from Samson, J., "Techniques of Vacuum Ultraviolet Spectroscopy", John Wiley & Sons, 1967)

## Reflection Grating

- Narrow beam
- Grazing incidence angle
- Grated reflection surface ('grating')
- Interference -> Spectral dispersion

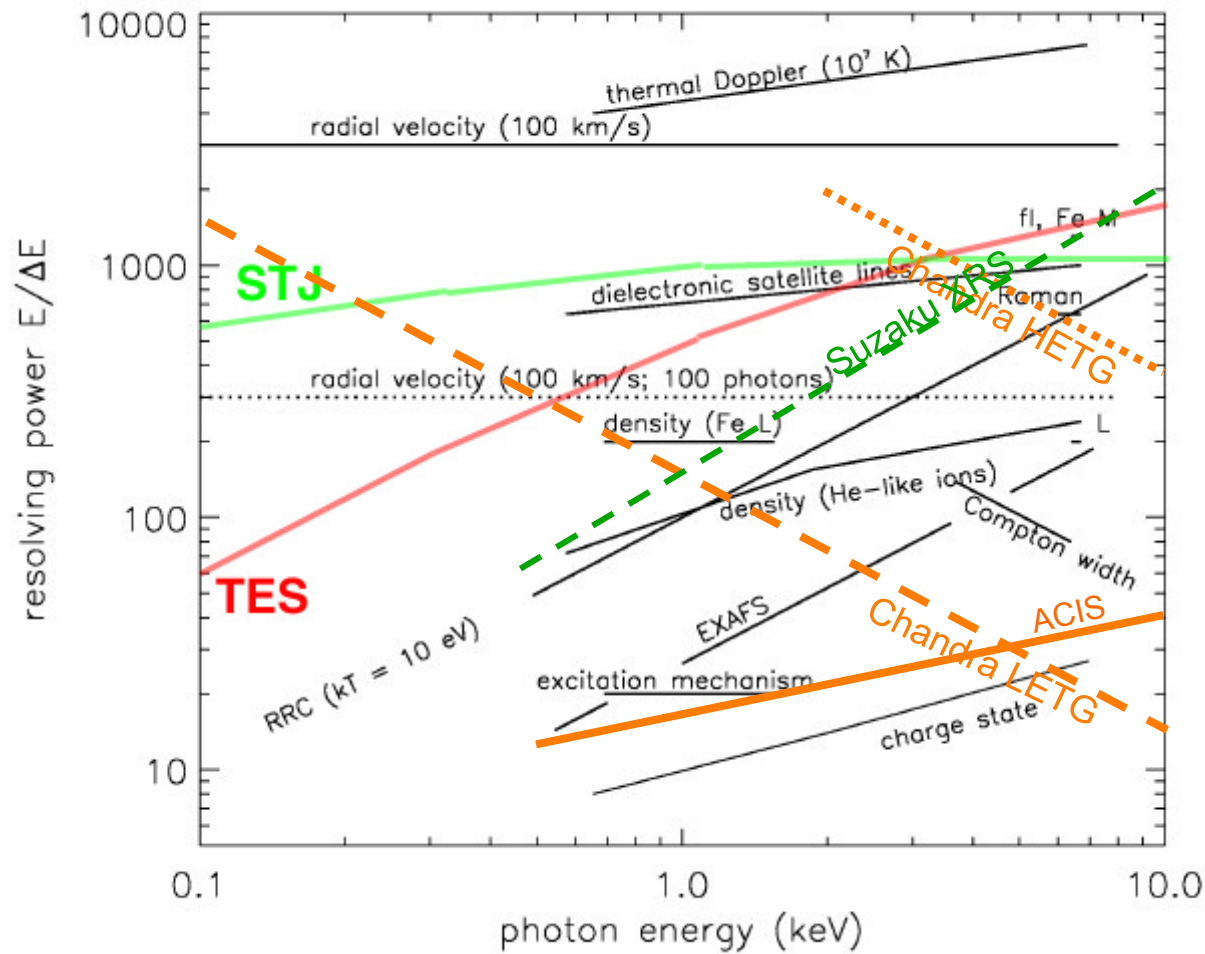


## Transmission Grating

"Transmission spectrometers"=

- Rings, each with a small transmission gratings
- Mounted on a Wolter telescope
- Detector placed on the 'Rowland circle'

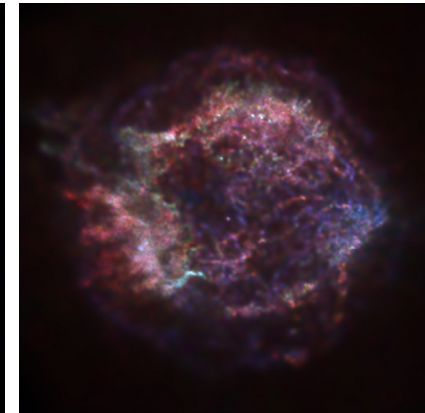
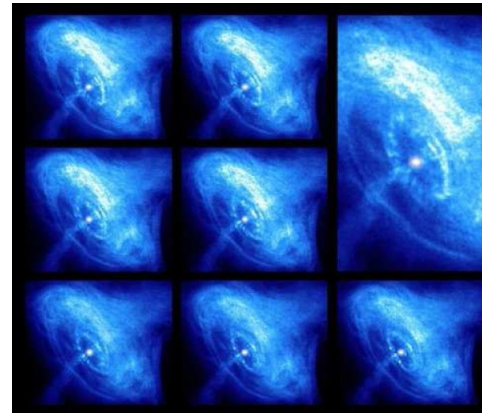
# X-ray Spectroscopy Science



# Achievements (examples)

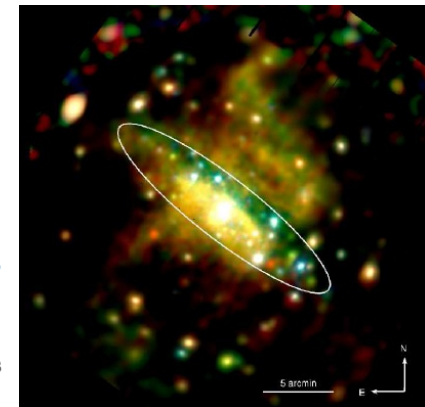
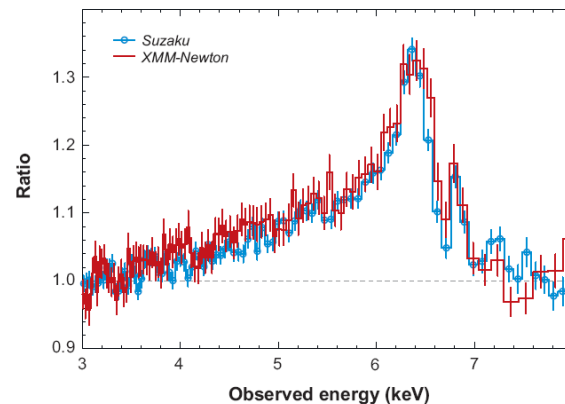
## ★ Chandra

☞ High-Resolution Imaging  
Crab PWN  
Cas A SNR



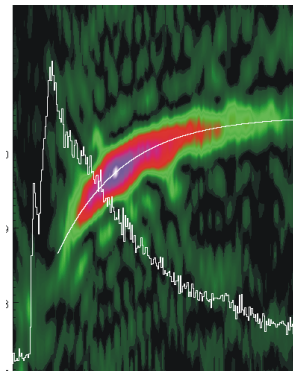
## ★ XMM-Newton

☞ Fe K-Line Spectra (->BH),  
AGN Spectral Images



## ★ RXTE

☞ Bursts on Rapidly-Rotating  
Neutron Stars,  
Transients





# X-ray Telescopes - Summary



- **Legacy**

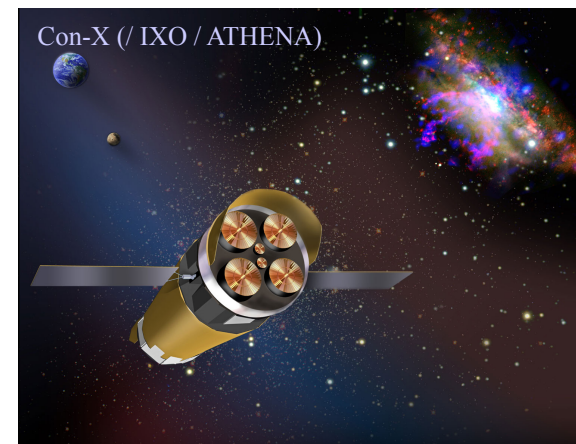
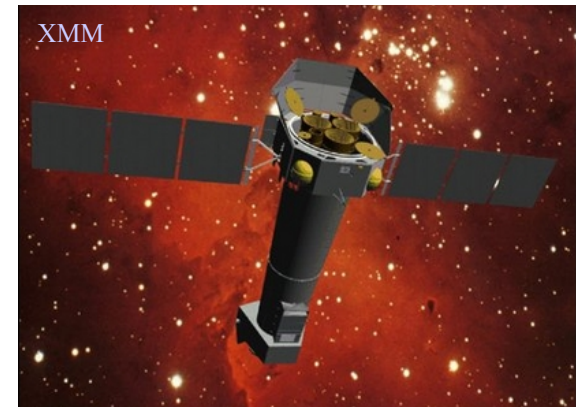
- ★ Uhuru/SAS-2 (1970-73), HEAO-1 (1977-79)
- ★ HEAO-2/Einstein (1978-81)
- ★ EXOSAT (1983-86)
- ★ ROSAT (1990-99)
- ★ ASCA (1993-2001), BeppoSAX (1996-2002)
- ★ RXTE (1995-2010)

- **Current**

- ★ **Chandra (1999-**
- ★ **XMM-Newton (1999-**
- ★ **Swift (2004-**
- ★ **Suzaku (2005-**

- **Prospects**

- ★ **ESA Cosmic Vision (*tbc!*)**
  - ☞ LOFT (high-resolution timing)
  - ☞ Athena (high-area & spectroscopy)
- ★ **National:**
  - ☞ NuStar (US), Astrosat (India), eRosita (D), Astro-H (J)



# Summary

## ★ X-ray Telescopes Use Nested Grazing-Incidence Mirrors

### ★ Typical Telescope Performances:

|                       |   |
|-----------------------|---|
| ☞ Energy Ranges       | 0.1 - 50 keV  |
| ☞ Sensitivities       | $10^{-15}$ erg cm <sup>-2</sup> s <sup>-1</sup> ; ~100 cm <sup>2</sup> effective area |
| ☞ Imaging Resolution  | few arcsec  |
| ☞ Field of View Size  | 10-20 arcmin (~deg for timing-only)   |
| ☞ Spectral Resolution | ~few 100  |
| ☞ Timing Resolution   | 10ms ... 10ms   |

### ★ Next Generation:

- ☞ Spatial Resolution ~few arcsec
- ☞ Spectral Resolution ~eV
- ☞ Energy Range 0.1 keV... up to ~70 keV
- ☞ Sensitivities  $< 10^{-19}$  erg cm<sup>-2</sup> s<sup>-1</sup> (examples ~XEUS/IXO Proposal, 0.1-40 keV range)



# The Experimental Task in the 10 keV ... 10 GeV Energy Range

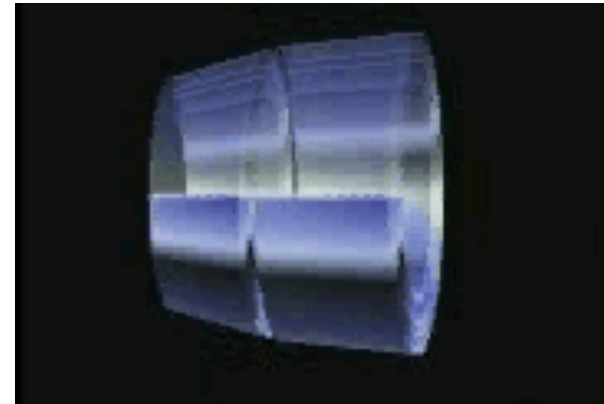
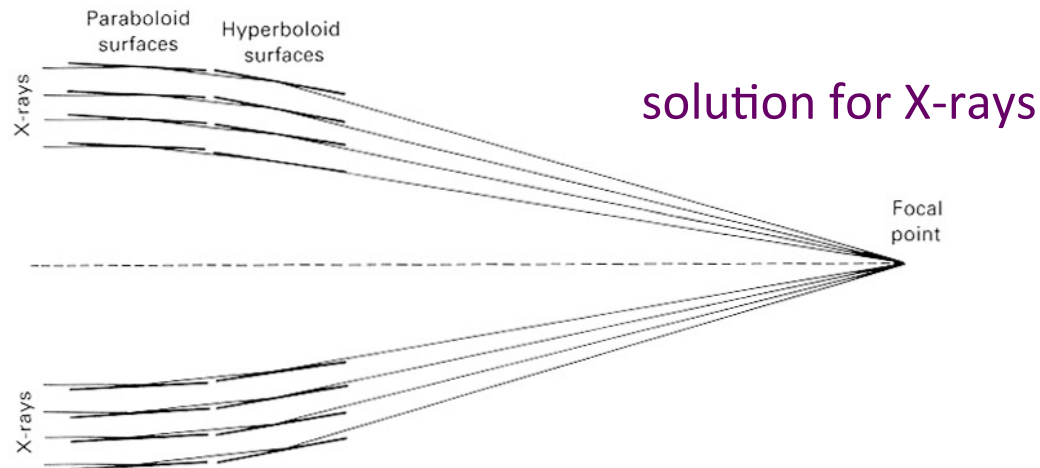
- **Sources, Cosmic Gamma Radiation:**
  - ☆ **Typical Intensities  $\sim 10^{-3} \dots 10^{-6} \text{ ph cm}^{-2} \text{ s}^{-1}$**
  - ☆ **Continuum Radiation, Lines of Largely-Different Widths**
  - ☆ **Embedded / Occulted Sources**
  - ☆ **Examples:**
    - ☞ **Active Galaxies and Black-Hole Radiation Phenomena**
    - ☞ **Hot Plasma Supernova Remnants**
    - ☞ **Interstellar-Medium Interactions**
    - ☞ **Cosmic Background Radiation Spectrum**
- **Instrumental Constraints:**
  - ☆ **Low Interaction Cross Sections**
  - ☆ **No/Problematic Reflecting Surfaces**
  - ☆ **Instrumental Background**

# HE Telescopes: Try Collecting Radiation

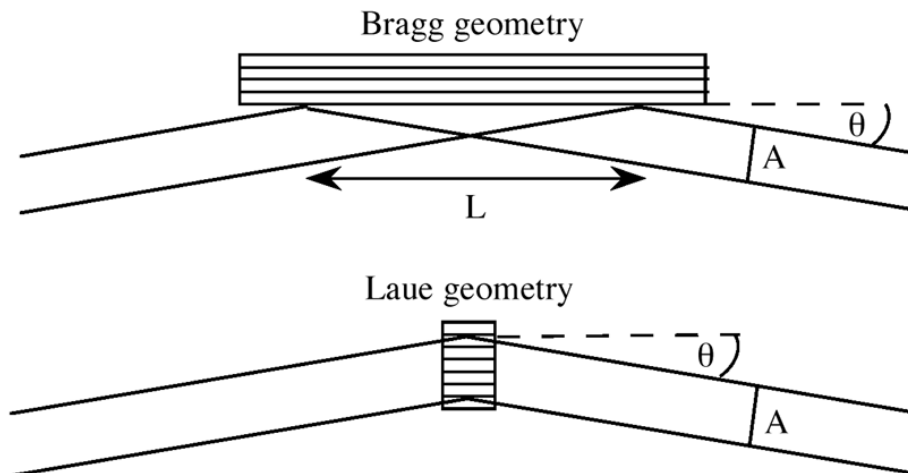
## ★ Why Concentrating Incident Radiation:

- **Signal**  $\sim$  **Telescope Area**
- **Background**  $\sim$  **Detector Volume**

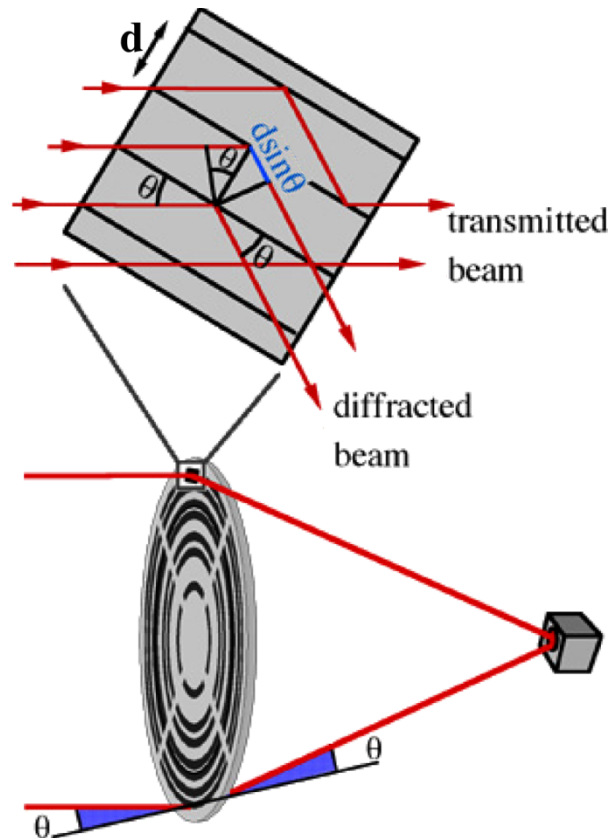
👉 **Signal/Background Ratio Improves with Radiation Concentration**



**gamma-ray analogue:**



# Focusing Gamma-Rays: Laue Lens Telescope



$$\lambda(511 \text{ keV}) = 2.42632 \cdot 10^{-2} \text{ \AA}$$

Bragg condition

$$2d \sin \theta = n \lambda$$

$$d[220] = 2.0004 \text{ \AA}$$

$$\text{Arcsin}(\theta/2d) = 0.347^\circ$$

Laue-type Gamma-ray lens

$$2\theta = 0.695^\circ$$

$$\text{ex. radius [220]} = 10.1 \text{ cm}$$

$$\Rightarrow \text{focal length} = 8.2 \text{ m}$$

narrow band Laue lens :

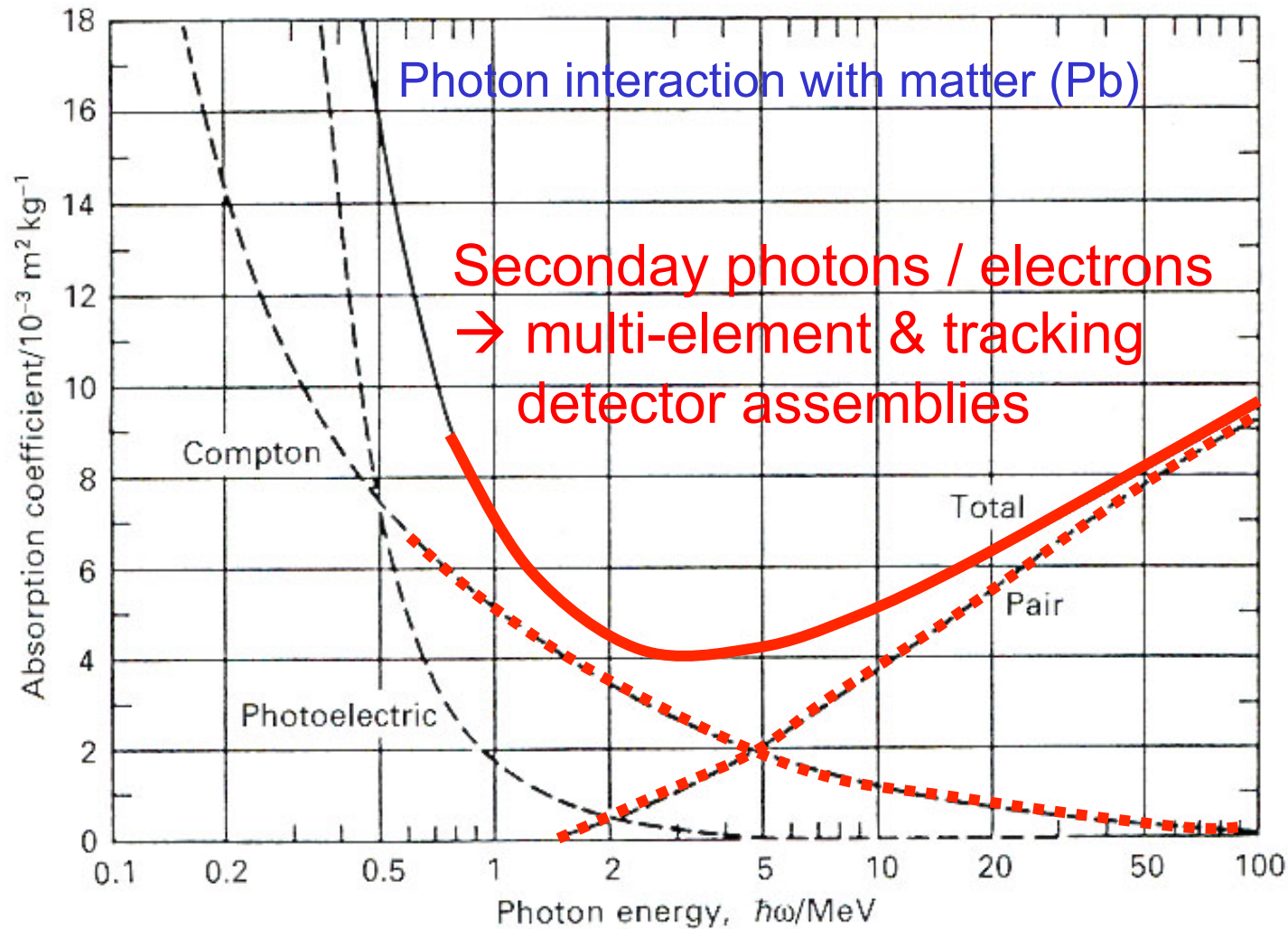
broad band Laue lens :

higher orders at larger radii (CLAIRE)

most efficient order at all radii (MAX)

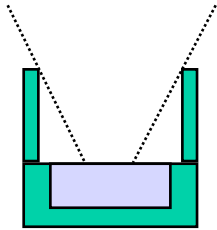
*courtesy P.von Ballmoos*

# Astronomical Gamma-Ray Telescopes: Interaction of HE Photons with Matter



-> Secondary Particles ... → e.m. cascade

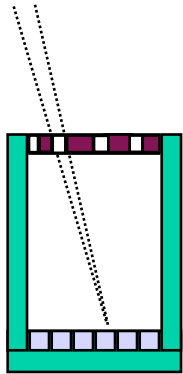
# MeV Range Gamma-Ray Telescope Principles



- **Simple Detector (& Collimator)**

(e.g. HEAO-C, SMM, CGRO-OSSE)

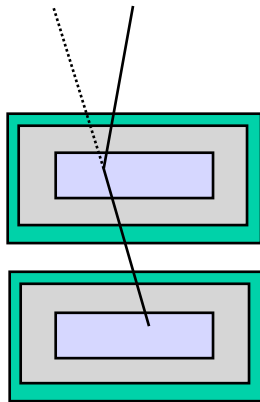
Spatial Resolution (=Aperture) Defined Through Shield



- **Coded Mask & Detector Array**

(e.g. SIGMA, INTEGRAL, SWIFT)

Spatial Resolution Defined by Mask & Detector Elements Sizes



- **Compton Telescopes**  
(Coincidence-Setup of  
Position-Sensitive Detectors)

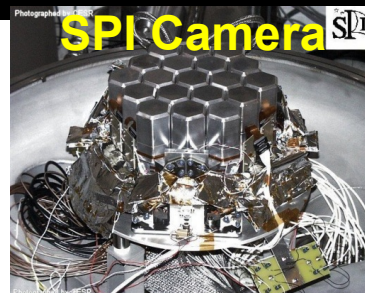
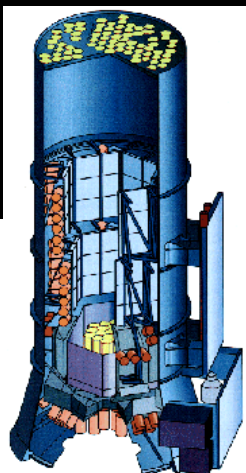
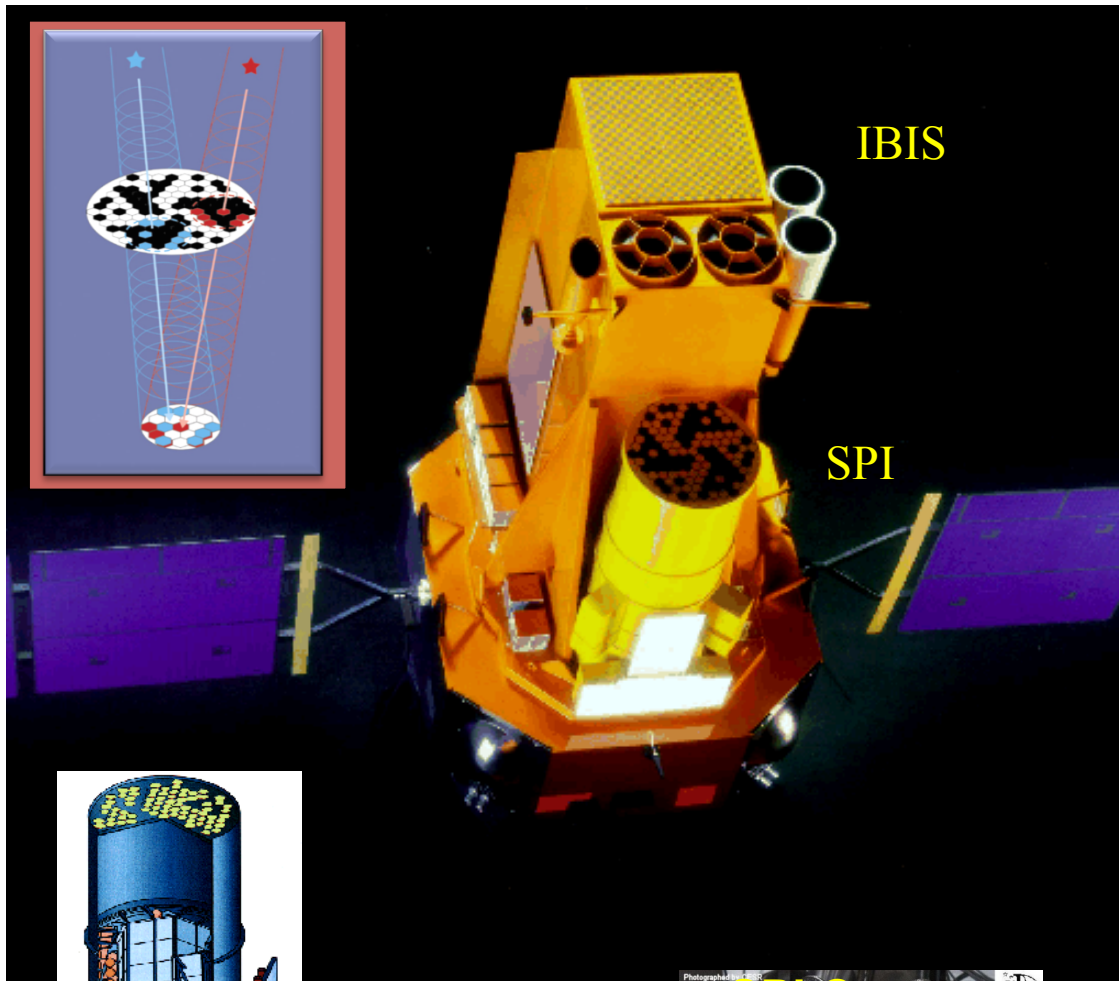
(e.g. CGO-COMPTEL, MEGA, ACT,...)

Spatial Resolution Defined by Detectors' Spatial Resolution

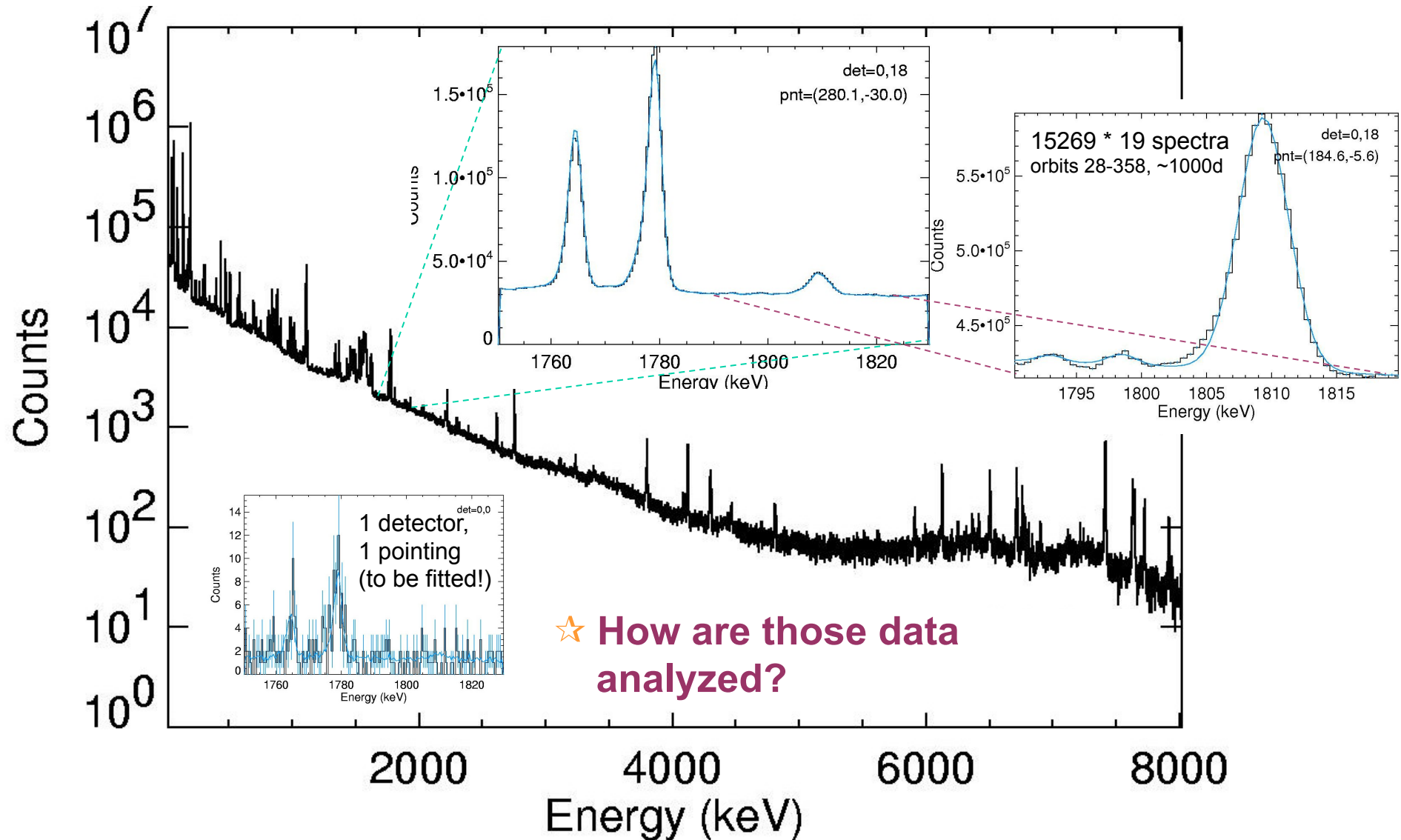
Achievable Sensitivity:  $\sim 10^{-5} \text{ ph cm}^{-2} \text{ s}^{-1}$ , Angular Resolution  $\sim \text{deg}$



# INTEGRAL „Imagers“

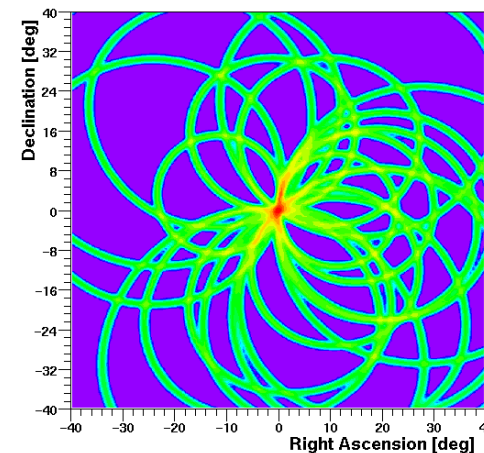
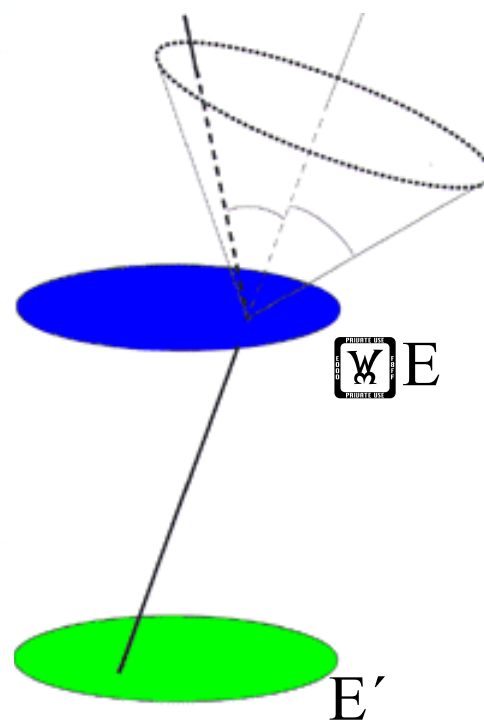
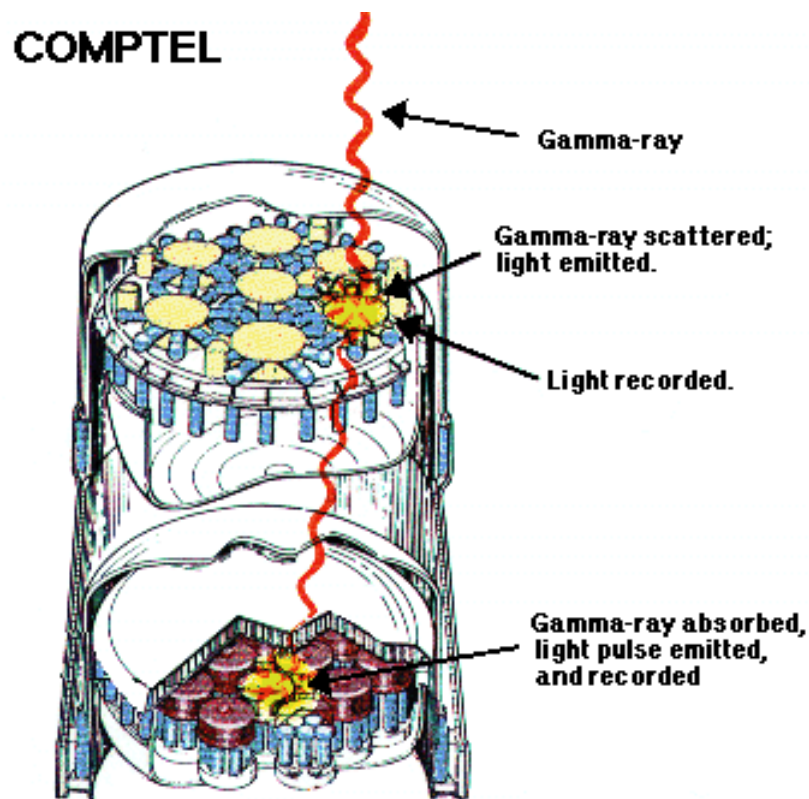


# Energy Spectra: Characteristic Examples



# Compton Telescope

## Compton Scattering: Coincidence Experiments

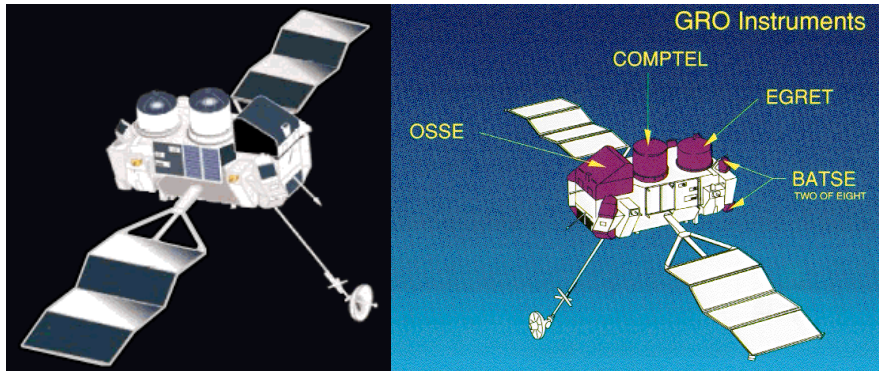


$$E' = \frac{E}{1 + \frac{E}{m_e c^2} (1 - \cos \theta)}$$

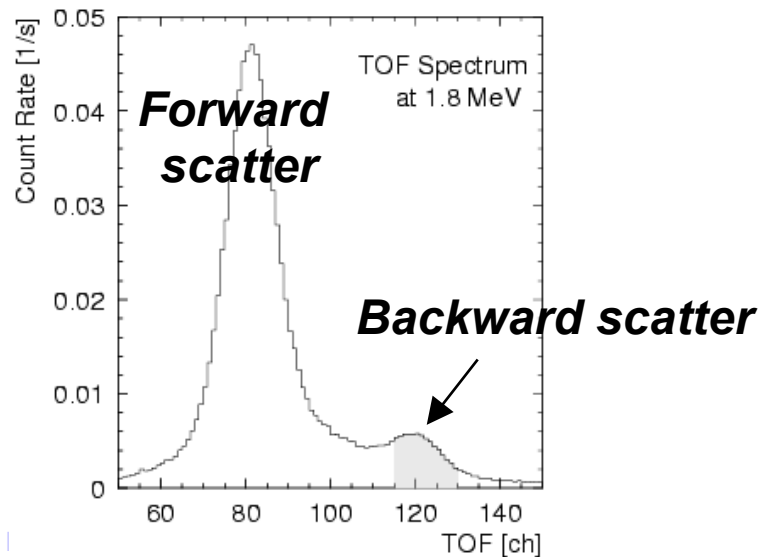
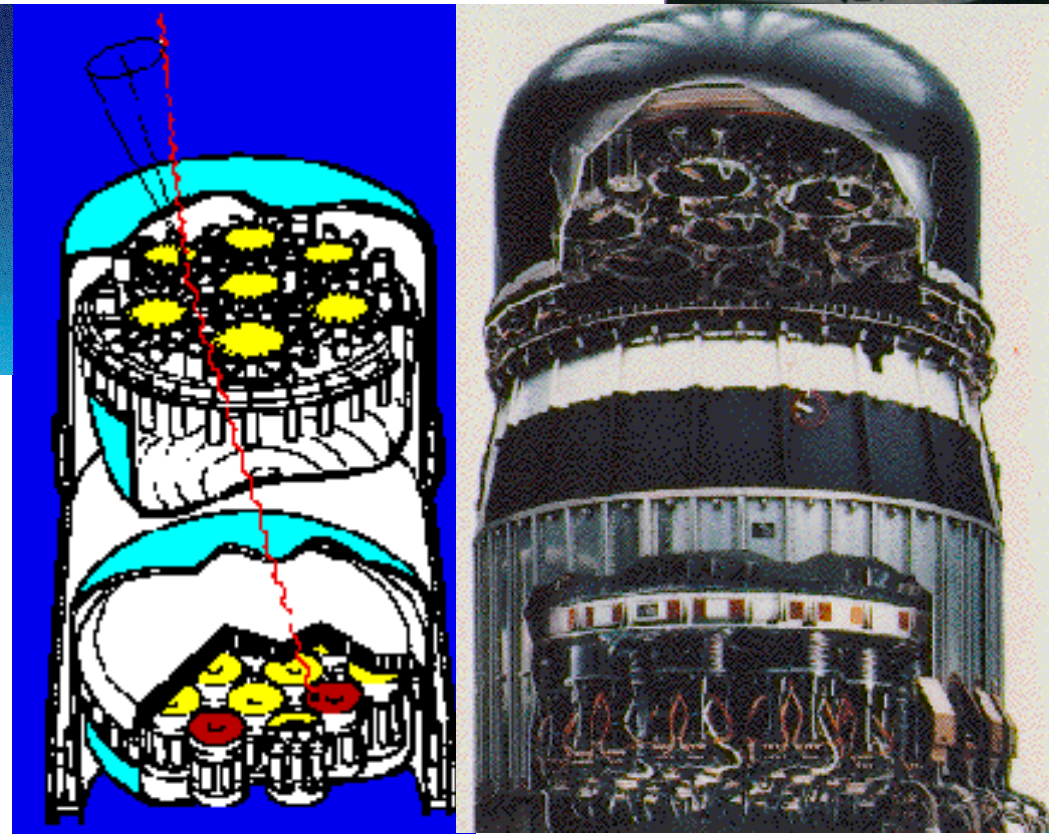
$$\varphi_{\text{geometric}} = \arccos \left\{ 1 + m_e c^2 \left( \frac{1}{E_\gamma} - \frac{1}{E_\gamma - \Delta E} \right) \right\}$$



# Pioneering Space Compton Telescope: COMPTEL on CGRO (1991-2000)



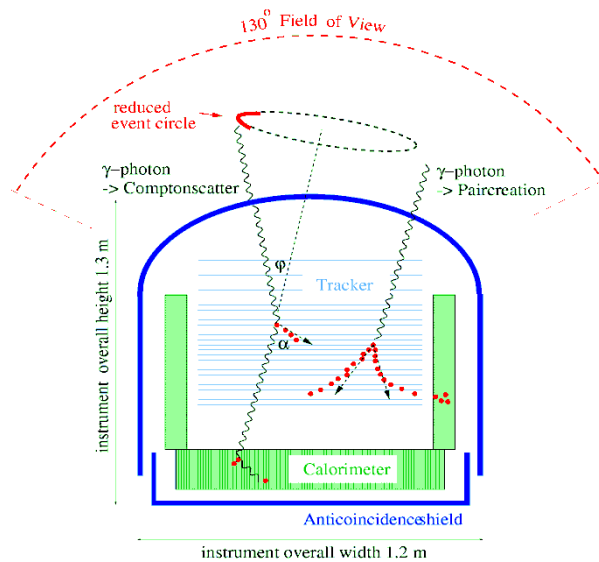
Interaction sequence obtained by  
time-of-flight (TOF) measurement.



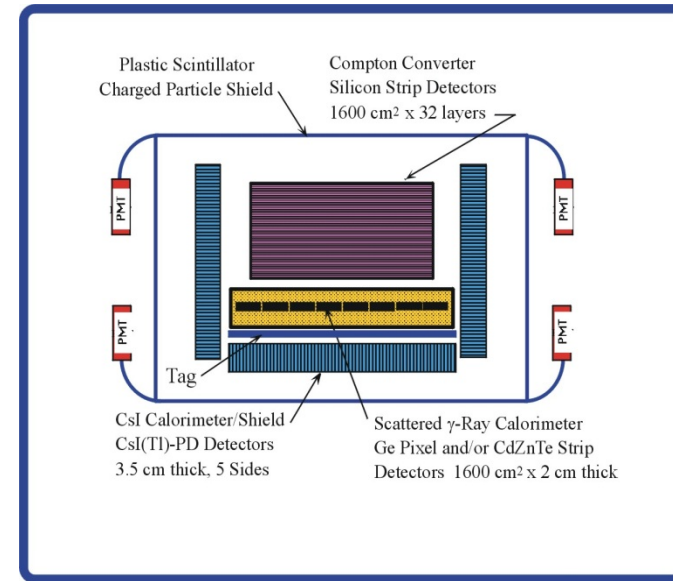
Advantage: clear separation of forward and  
backward events.

Disadvantage: low efficiency due to solid  
angle effect.

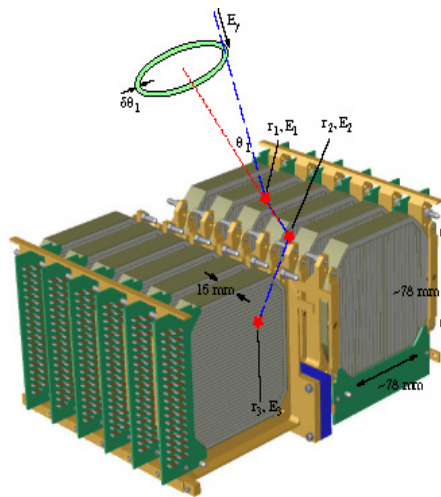
# Compton Telescopes



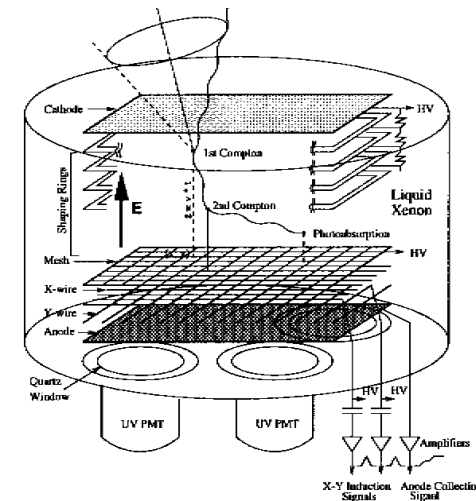
MEGA



TIGRE



Nuclear Compton Telescope  
(NCT)



LXeGRIT

FIGURE 1. Schematic of the liquid xenon time projection chamber

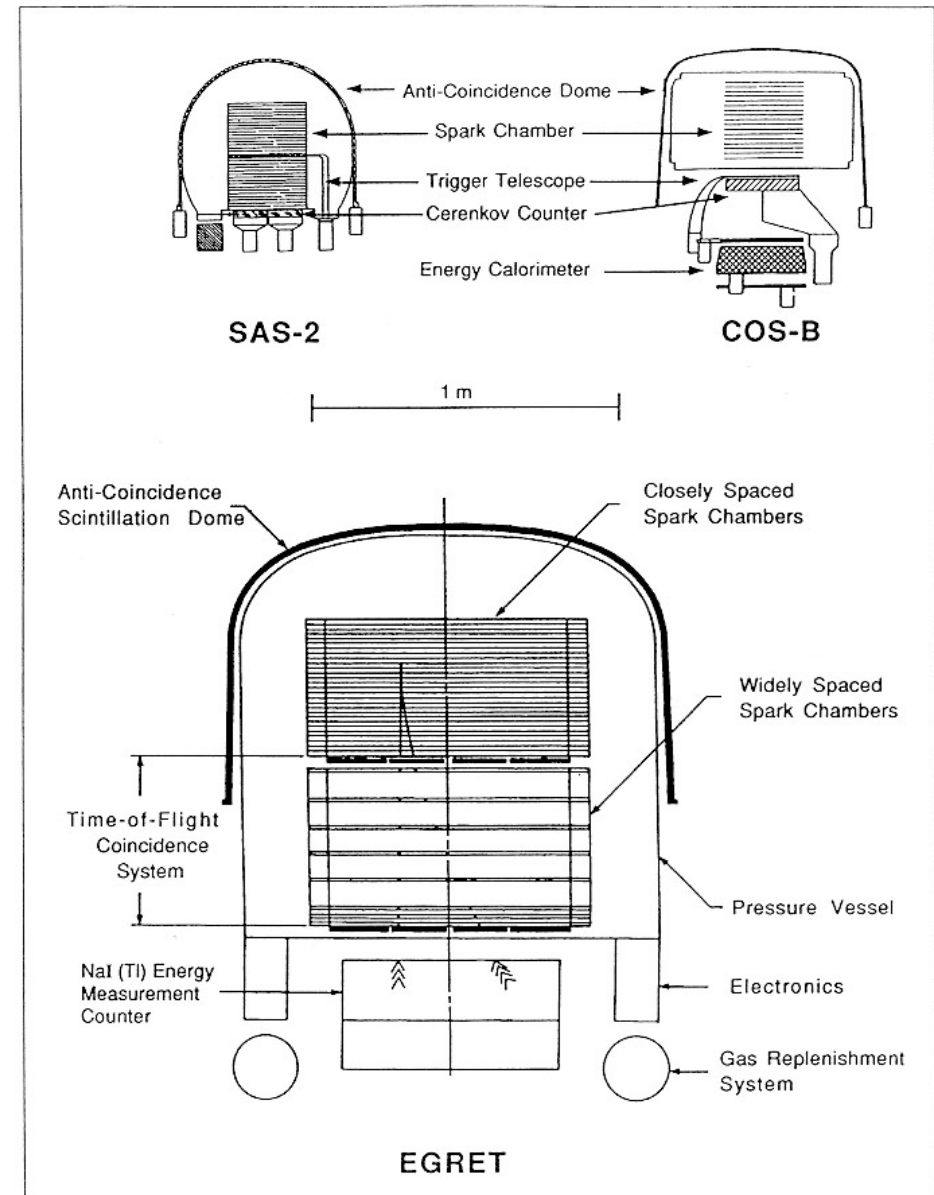
# Spark Chambers



The Pair Regime:

Tracking Ionization Paths

$E \sim 50 \text{ MeV} - \text{few GeV}$



# Detecting Cosmic High-Energy Photons

- *The Physical Processes behind...*

- ★ **UV and X-Rays:**

- ☞ Space-resolved Charge Collection in Imaging Plane of Focussing Optics
- ☞ Using Photo-Electric Effect, i.e. Atomic-Ionization Charges

- ★ **Low-Energy Gamma-Rays**

- ☞ Energy Transfers in Photon Collisions -> High-Energy Secondaries
- ☞ Compton Electron Detection & Tracking

- ★ **Medium-Energy Gamma-Rays**

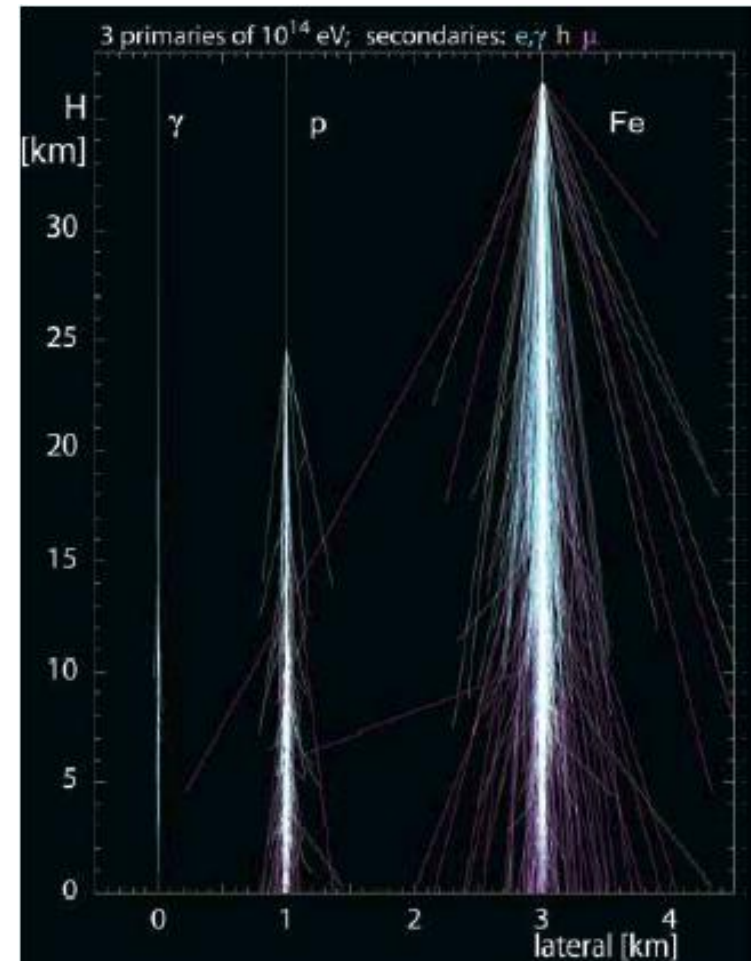
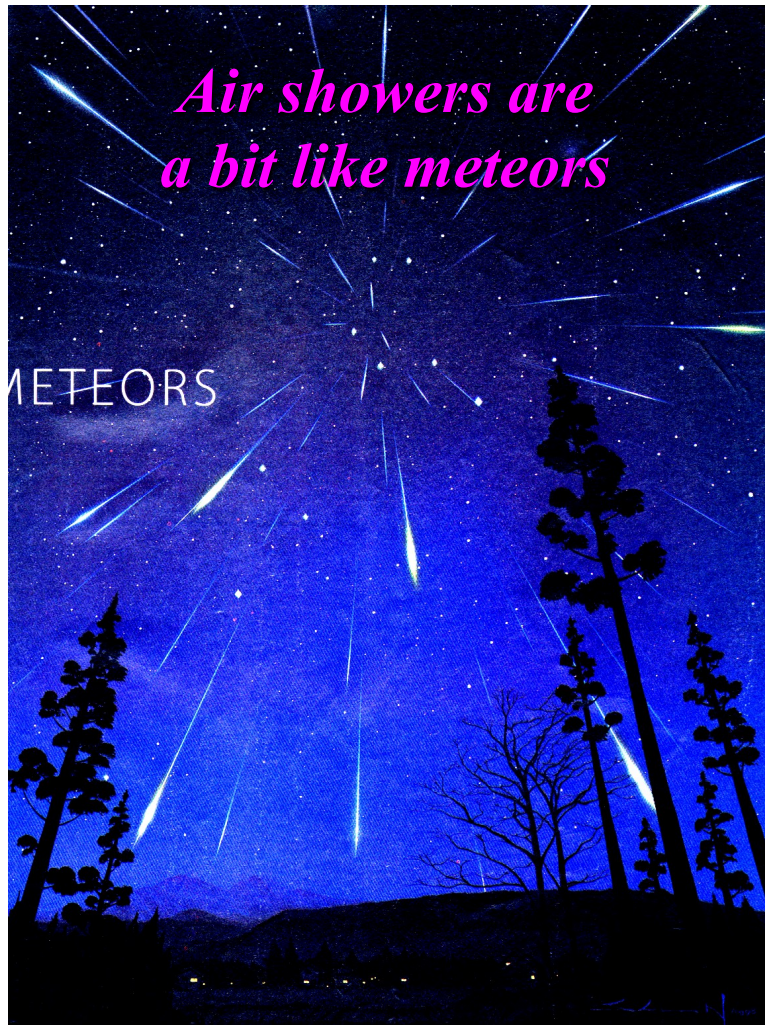
- ☞ Pair Production as Most-Likely Initial Interaction with Matter
- ☞ Trace Ionization Tracks of Secondary  $e^-e^+$

- ★ **High-Energy Gamma-Rays**

- ☞ **Electromagnetic Cascade is Extended & Penetrating**
- ☞ **Use Earth Atmosphere as Interaction Volume, Observe Showers**



# What is measured?

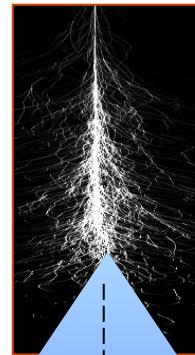


- appearance of shower
  - primary particle (photon or hadron)
- penetration depth
  - heavy or light particle
- particles detected on ground
  - e.g. mass estimate (from ratio of myon to electron number)

# Čerenkov Telescopes

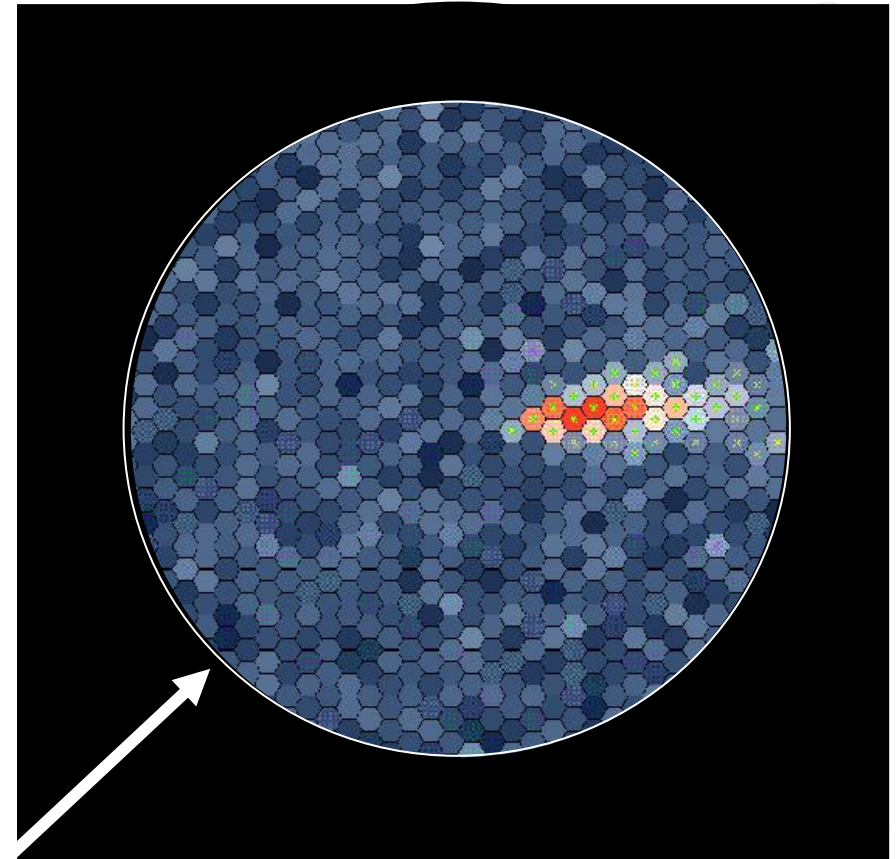
Gamma-ray

Particle  
Shower



$\sim 1^\circ$

$\sim 120$  m

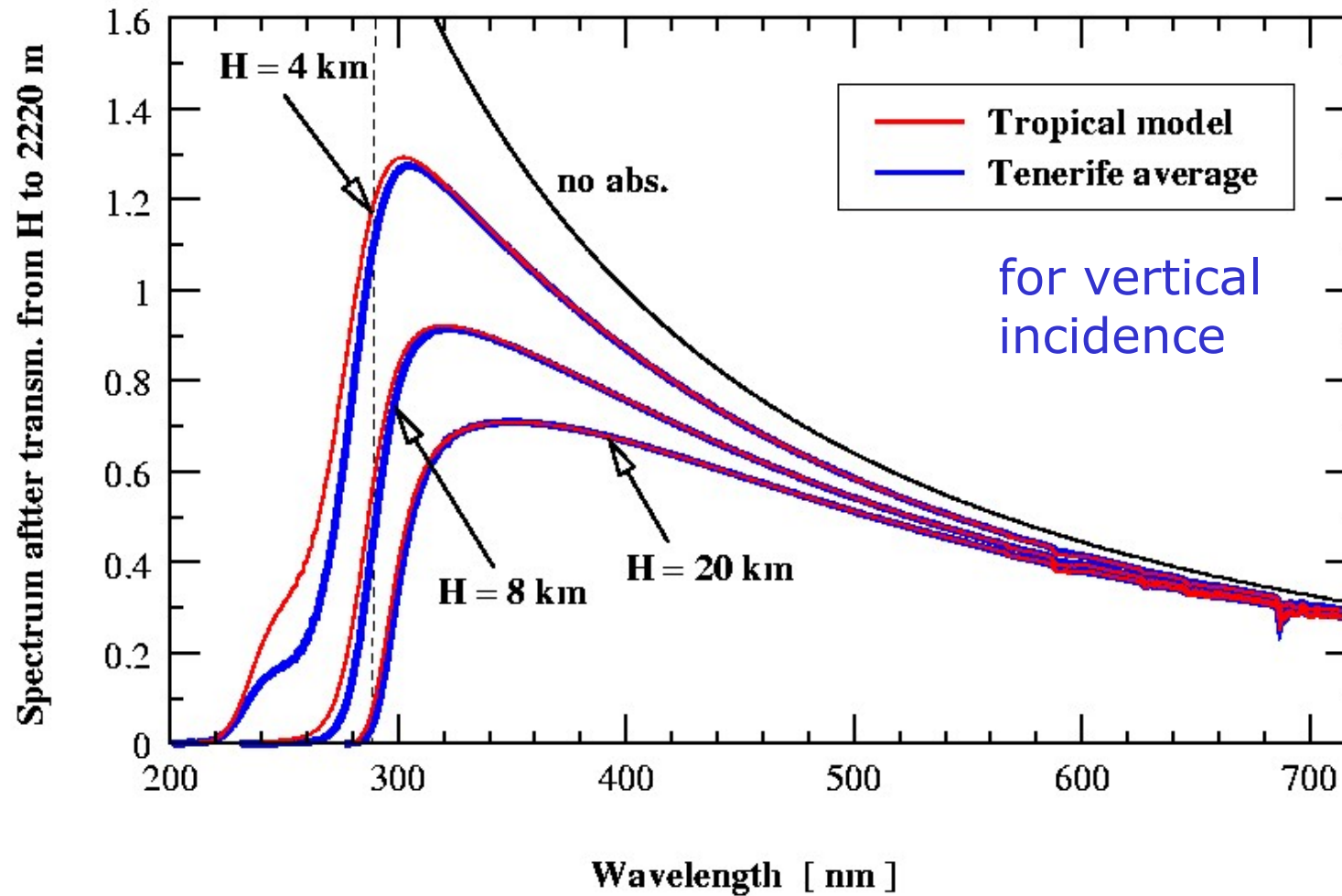


at 1 TeV

$\sim 100$  photons/m<sup>2</sup>  
(300 – 600 nm)

$\sim 10 - 20$  photoel./ m<sup>2</sup>

# Spectrum of Cherenkov light

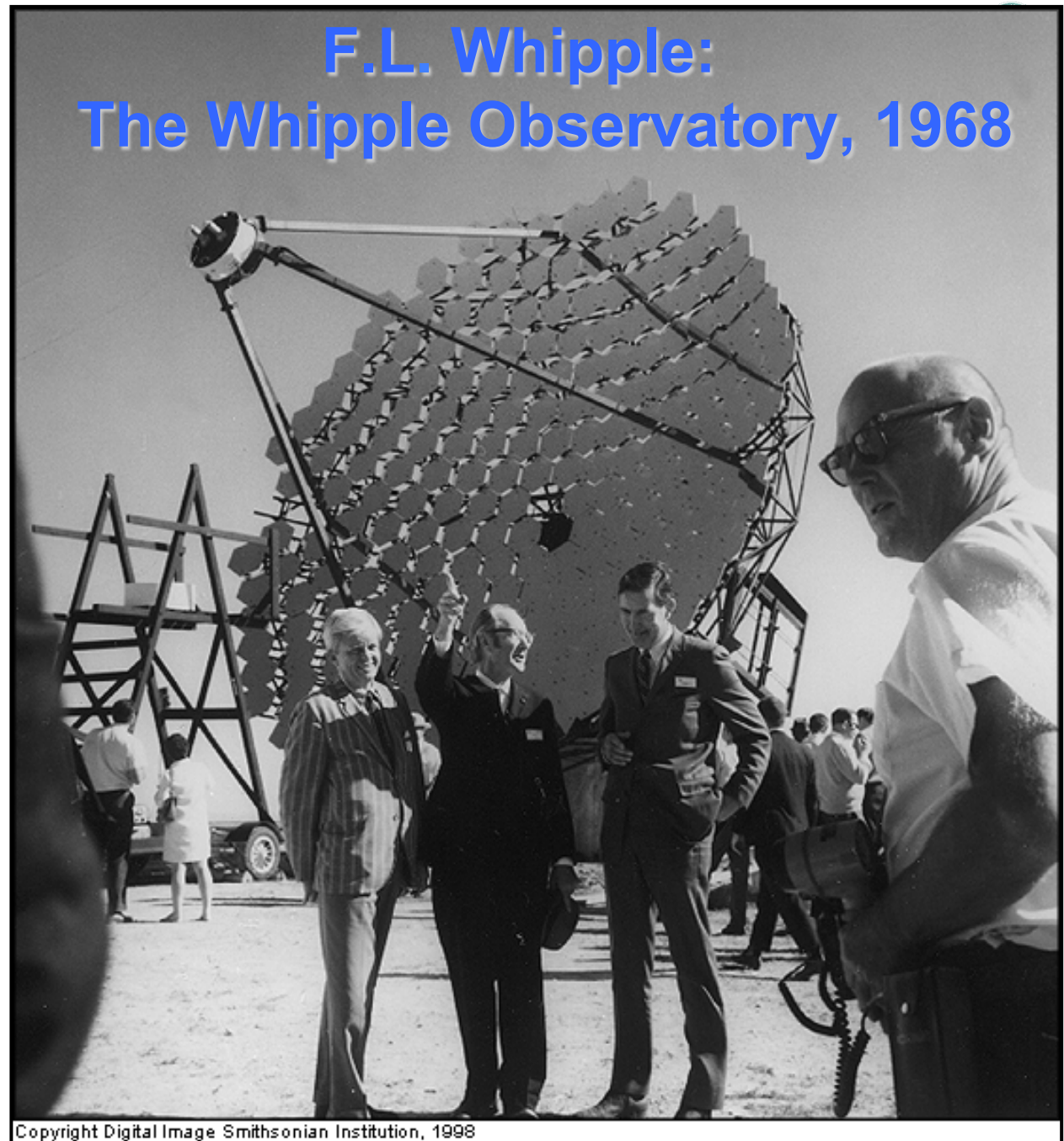




Fred Lawrence Whipple  
 (\* 5.11.1906 in Red Oak/Iowa;  
 † 30.8.2004 in Cambridge/USA)

Detection of  
 the Crab Nebula (1989):

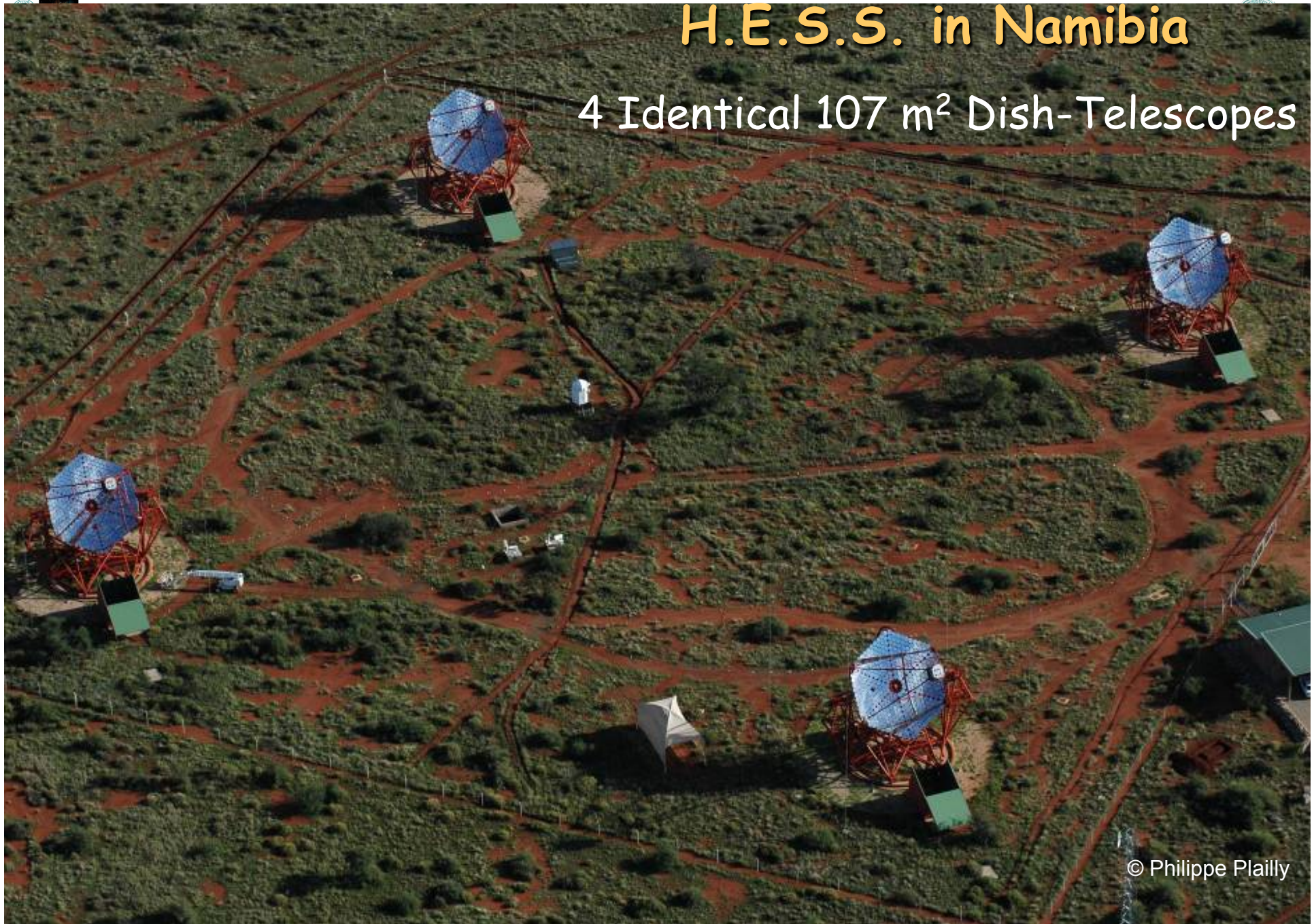
50 h observation time  
 for a  $5\sigma$  signal





# H.E.S.S. in Namibia

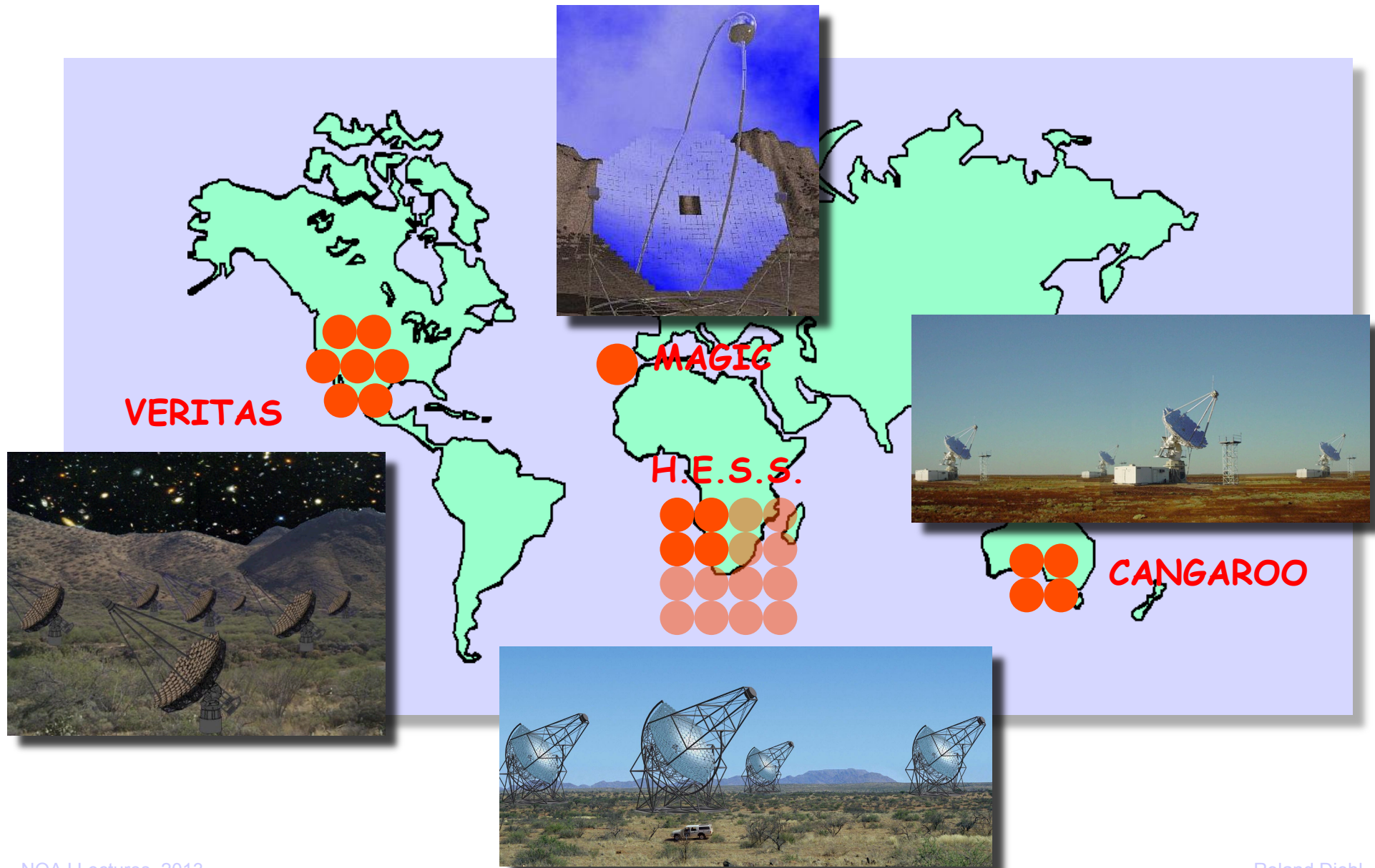
4 Identical 107 m<sup>2</sup> Dish-Telescopes



© Philippe Plailly



# Major IACT projects in high-energy $\gamma$ -ray astronomy



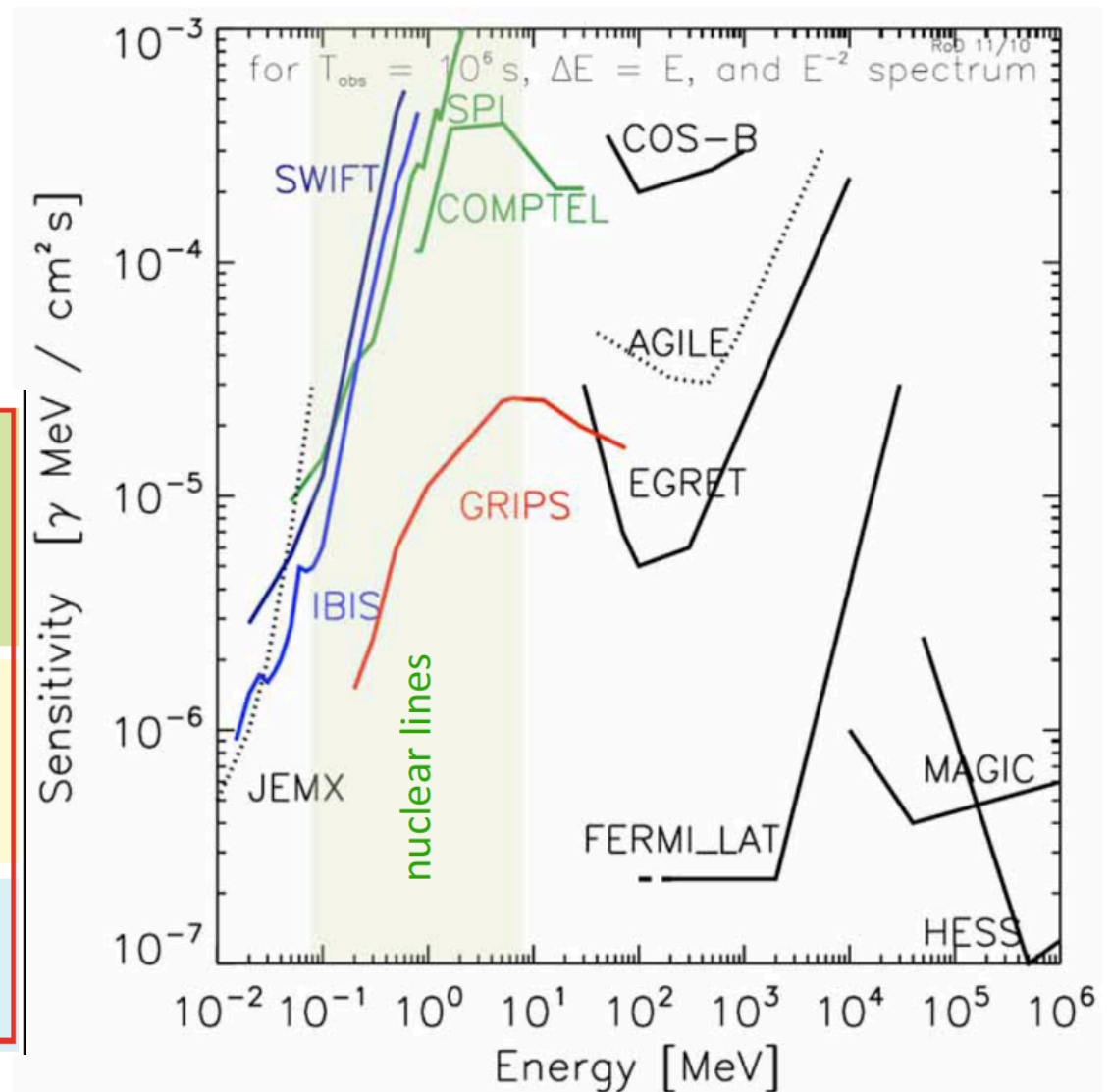
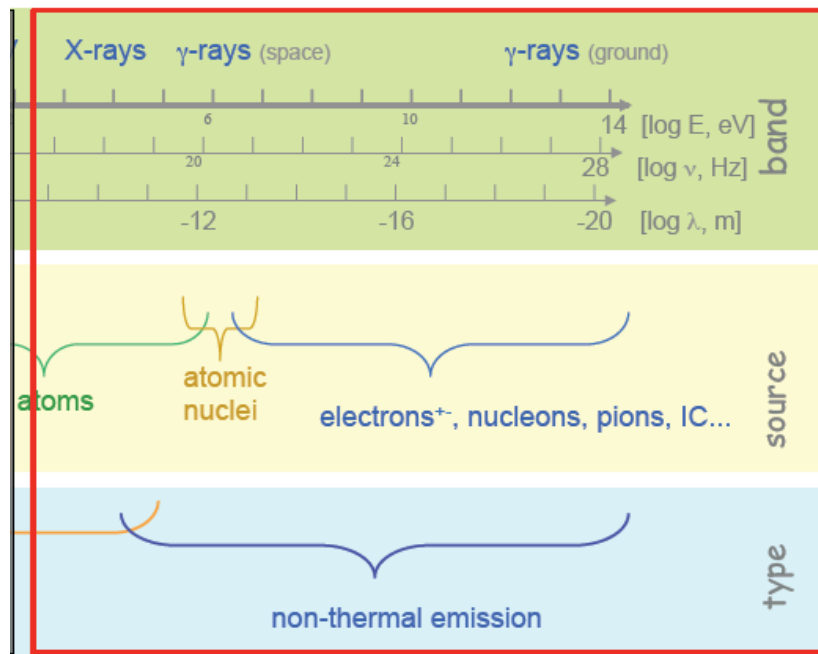
# HE Telescope Sensitivities



- Dynamic Range  
~10-12 Decades

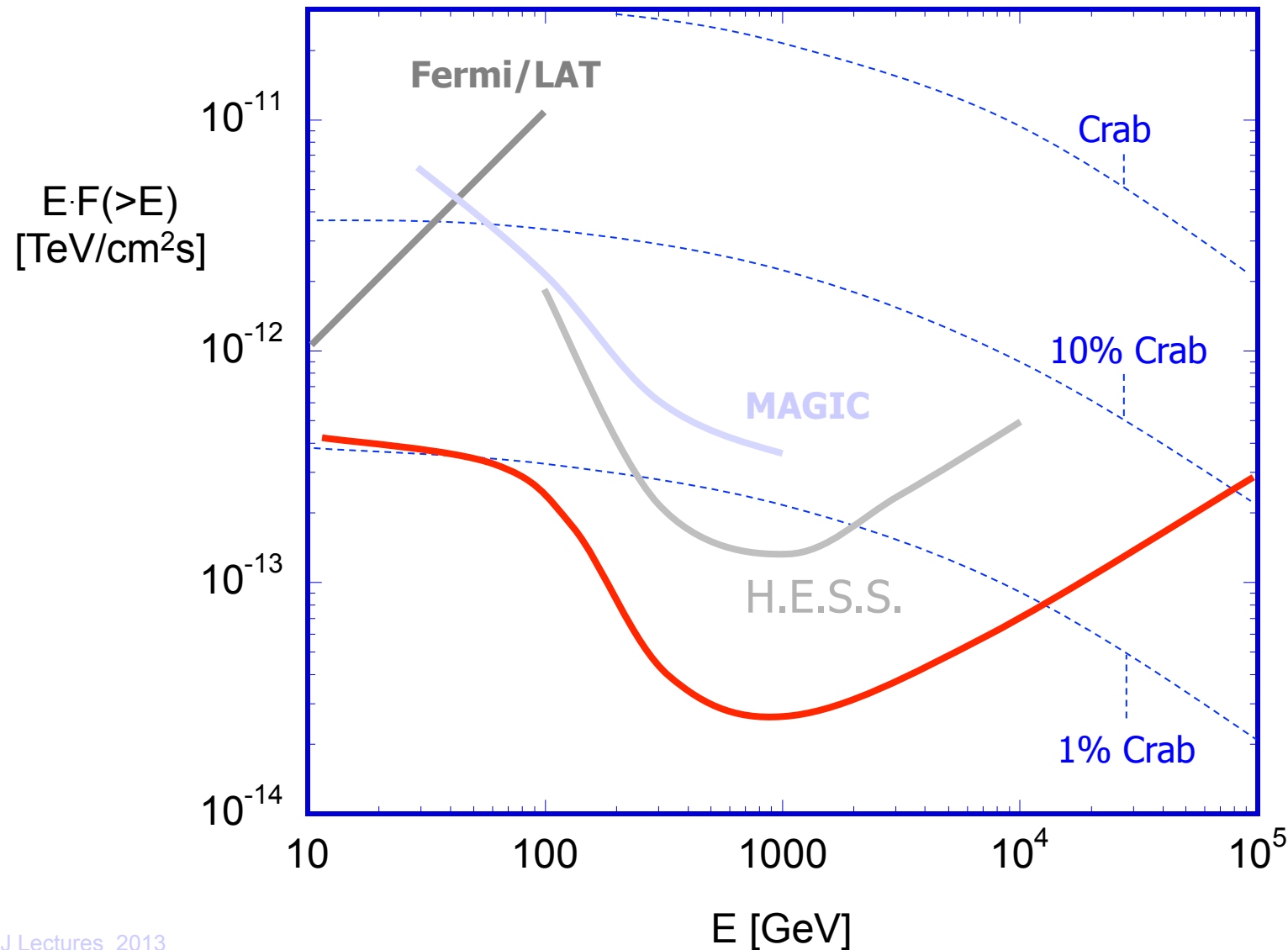
➡ Different Techniques  
Across the HE Band

➡ Challenge:  
Nuclear-Line Regime

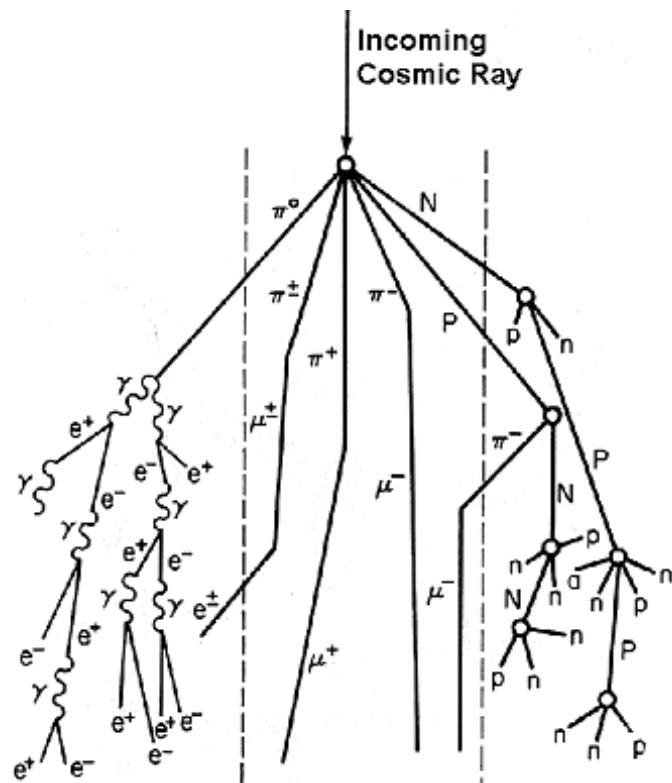


# The future: Cerenkov Telescope Array (CTA)

An International Collaboration of all IACT Expert Groups



# Air Shower Experiments



## KEY

|       |         |          |          |
|-------|---------|----------|----------|
| P     | Proton  | e        | Electron |
| n     | Neutron | $\mu$    | Muon     |
| $\pi$ | Pion    | $\gamma$ | Photon   |

Air showers consist of 3 components:

- **hadronic component**  
primary proton scatters off atmospheric nuclei, thereby producing protons, neutrons, pions, kaons, ...
- **myonic component**  
the decay of charged pions and kaons generates myons
- **electromagnetic component**  
the decay of neutral pions generates  $\gamma$ 's, which initiate electromagnetic cascade through pair creation and bremsstrahlung



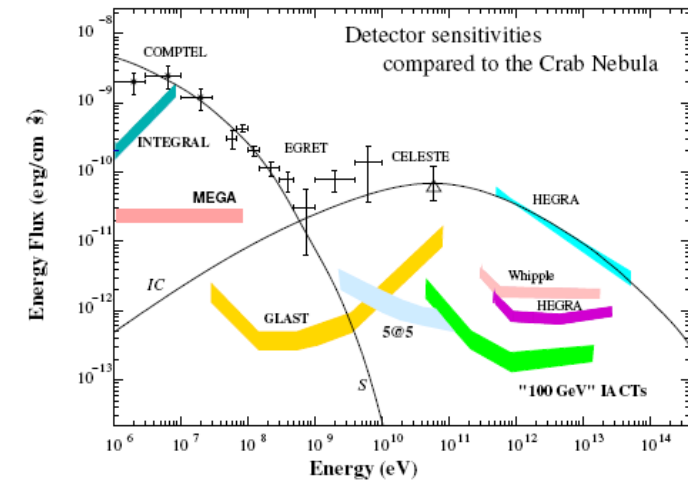
# Very-High Gamma-Ray Telescopes

## ★ Ground-Based

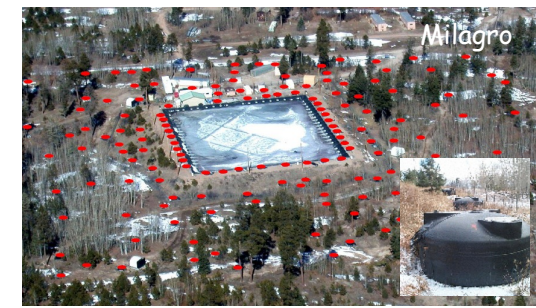
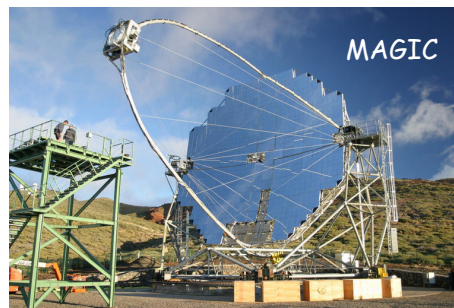
👉 Atmospheric Cerenkov Radiation Detectors

👉 Atmospheric Air Shower Detectors

| Experiment   | Type        | Location              | Altitude | Specifications           | Ref. |
|--------------|-------------|-----------------------|----------|--------------------------|------|
| CACTUS       | AC-Sampling | Barstow, USA          | 640m     | 144 x 42 m <sup>2</sup>  |      |
| CANGAROO-III | AC-Imaging  | Woomera, Australia    | 165m     | 4 x 78 m <sup>2</sup>    | [5]  |
| HESS         | AC-Imaging  | Gamsberg, Namibia     | 1800m    | 4 x 110 m <sup>2</sup>   | [6]  |
| MAGIC        | AC-Imaging  | La Palma, Spain       | 2250m    | 1 x 226 m <sup>2</sup>   | [7]  |
| PACT         | AC-Sampling | Pachmarhi, India      | 1075m    | 25 x 4.5 m <sup>2</sup>  | [8]  |
| SHALON       | AC-Imaging  | Tien Shan, Kazakhstan | 3338m    | 1 x 11 m <sup>2</sup>    | [9]  |
| STACEE       | AC-Sampling | Albuquerque, USA      | 1700m    | 64 x 37 m <sup>2</sup>   | [10] |
| TACTIC       | AC-Imaging  | Mt. Abu, India        | 1400m    | 1 x 9.5 m <sup>2</sup>   | [11] |
| VERITAS      | AC-Imaging  | Mt. Hopkins, USA      | 1275m    | 2 x 110 m <sup>2</sup>   | [12] |
| Whipple      | AC-Imaging  | Mt. Hopkins, USA      | 2250m    | 1 x 78 m <sup>2</sup>    | [13] |
| ARGO-YBJ     | Air Shower  | Yangbajing, Tibet     | 4300m    | 4000 m <sup>2</sup>      | [14] |
| GRAPES-III   | Air Shower  | Ooty, India           | 2200m    | 288 x 1 m <sup>2</sup>   | [15] |
| Milagro      | Air Shower  | Los Alamos, USA       | 2630m    | 4800 m <sup>2</sup>      | [16] |
| Tibet        | Air Shower  | Yangbajing, Tibet     | 4300m    | 761 x 0.5 m <sup>2</sup> | [17] |



- [5] T. Yoshikoshi *et al.*, Proc. 29th Int. Cosmic Ray Conf., Pune, 5, 343 (2005).
- [6] W. Hoffman, Proc. 29th Int. Cosmic Ray Conf., Pune, Review, Rapporteur and Highlight Papers, 10, 97 (2005).
- [7] R. Mirzoyan, Proc. 29th Int. Cosmic Ray Conf., Pune, 4, 23 (2005).
- [8] D. Bose *et al.*, Proc. 29th Int. Cosmic Ray Conf., Pune, 4, 343 (2005).
- [9] V.G. Sinitsyna *et al.*, Proc. 29th Int. Cosmic Ray Conf., Pune, 4, 395 (2005).
- [10] J. Kildea *et al.*, Proc. 29th Int. Cosmic Ray Conf., Pune, 4, 89 (2005).
- [11] R.C. Rannot *et al.*, Proc. 29th Int. Cosmic Ray Conf., Pune, 4, 355 (2005).
- [12] J. Holder *et al.*, Proc. 29th Int. Cosmic Ray Conf., Pune, 5, 379 (2005).
- [13] J. Perkins *et al.*, Proc. 29th Int. Cosmic Ray Conf., Pune, 4, 423 (2005).
- [14] S. Vernetto *et al.*, Proc. 29th Int. Cosmic Ray Conf., Pune, 4, 375 (2005).
- [15] P.K. Mohanty *et al.*, Proc. 29th Int. Cosmic Ray Conf., Pune, 6, 21 (2005).
- [16] A. Smith, Proc. 29th Int. Cosmic Ray Conf., Pune, Review, Rapporteur and Highlight Papers, 10, 227 (2005).
- [17] M. Amenomori *et al.*, Proc. 29th Int. Cosmic Ray Conf., Pune, 4, 211 (2005).





## **- Astronomy with Cosmic Rays and Neutrinos -**

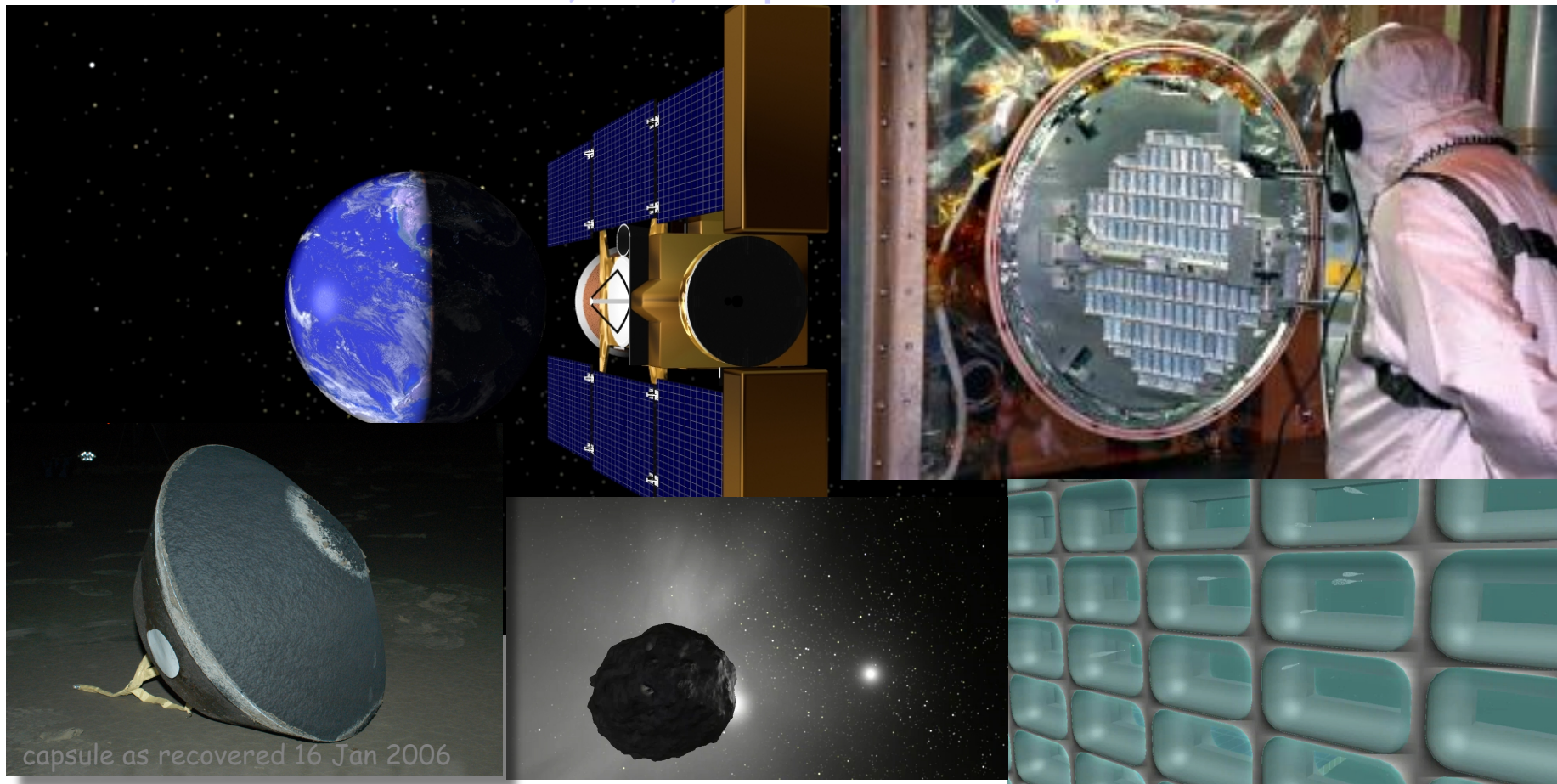
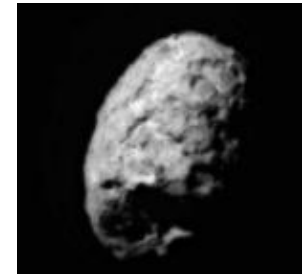
### **Cosmic Rays near Earth Neutrinos**

# Stardust Mission: Collecting Interplanetary Dust

- ★ Aerogel Layers Deposited in Interplanetary Space
- ★ Sample Return for Analysis in Terrestrial Laboratory

👉 "Stardust" Mission: Sample Return from Comet Wild

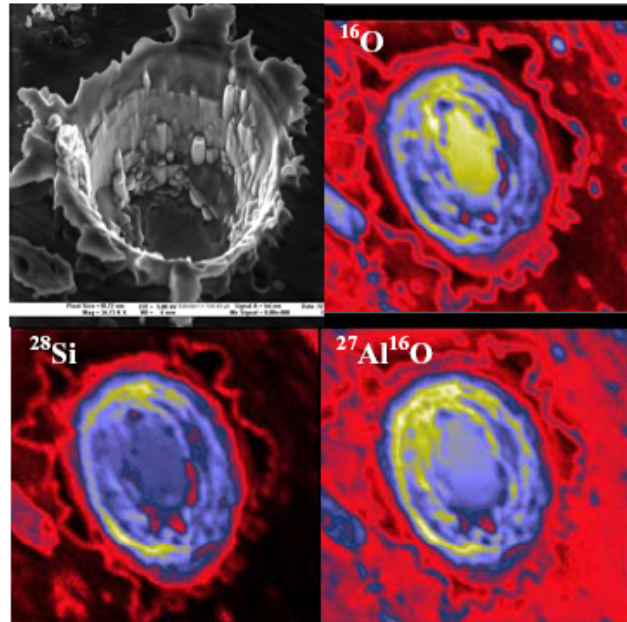
👉 launched Feb 7, 1999; sample return Jan 16, 2006



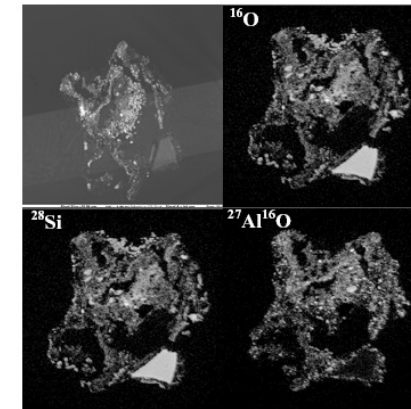
# Sample-Return Analyses



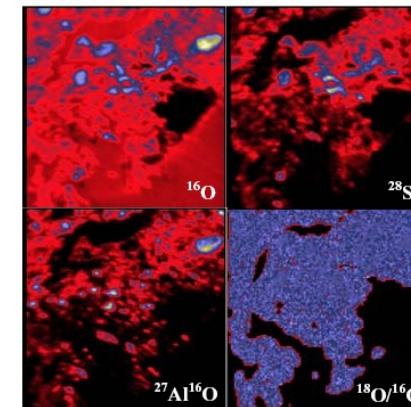
## ☆ Compare Crater Morphologies with Laboratory-Made Craters (Using Meteorite Grains)



**Figure 3.** SEM image (after NanoSIMS analysis) and NanoSIMS ion images of  $^{16}\text{O}$ ,  $^{28}\text{Si}$ , and  $^{27}\text{Al}^{16}\text{O}$  of a crater produced by an Allende projectile. Field of view is  $8 \times 8 \mu\text{m}^2$  in the ion images (from ref. 10).



**Figure 4.** SEM image and NanoSIMS ion images of  $^{16}\text{O}$ ,  $^{28}\text{Si}$ , and  $^{27}\text{Al}^{16}\text{O}$  of ultra-microtome section E237-7f-s3g6-E. Field of view is  $32 \times 32 \mu\text{m}^2$  in the ion images.



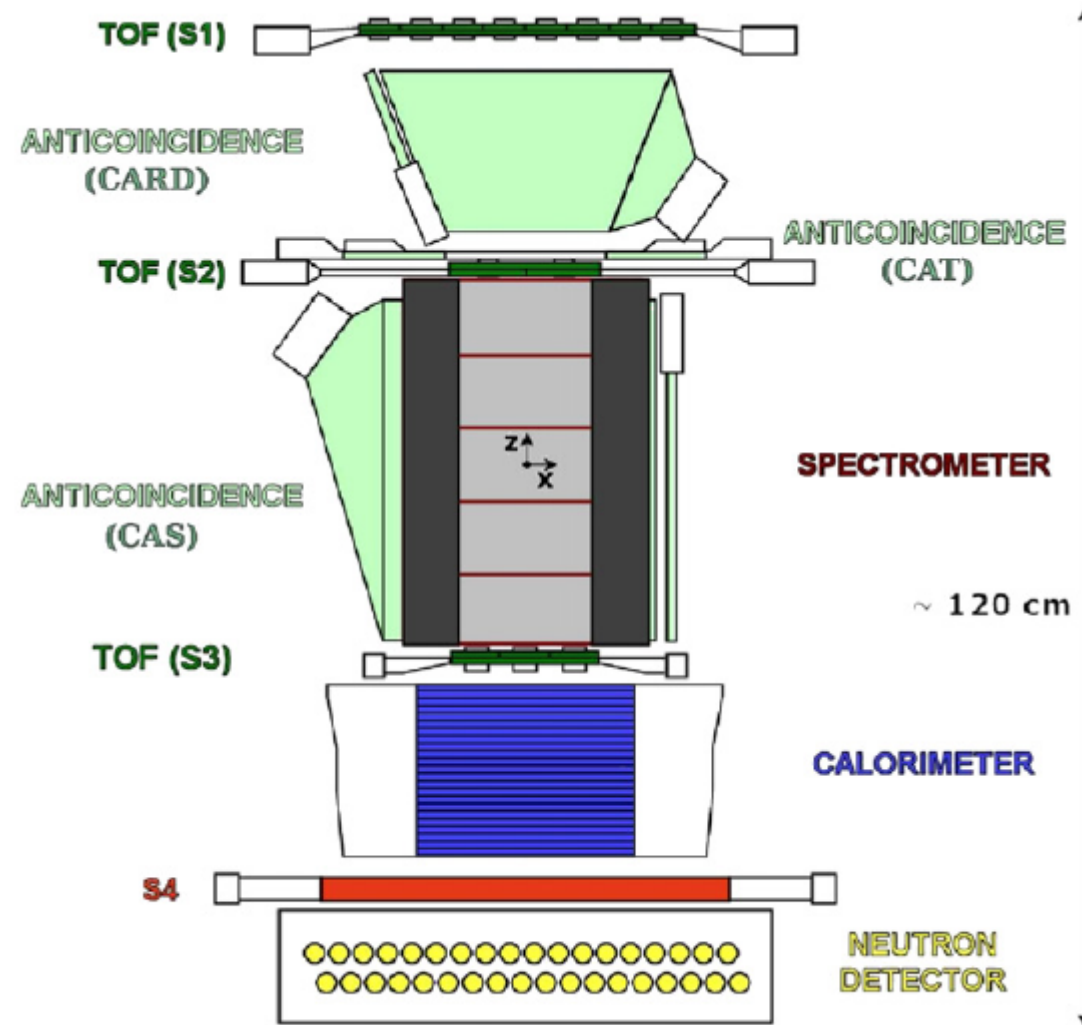
**Figure 5.** NanoSIMS ion images of  $^{16}\text{O}$ ,  $^{28}\text{Si}$ ,  $^{27}\text{Al}^{16}\text{O}$ , and  $^{18}\text{O}/^{16}\text{O}$  of a  $10 \times 10 \mu\text{m}^2$ -sized sub-area of ultra-microtome section E237-7f-s3g6-E.

## ☆ Analyze Samples Grains with Mass Spectrometers

# Cosmic Ray Particles in Space

## ★ PAMELA Satellite

👉 Launched 2008







# The Alpha Magnetic Spectrometer



## ★ AMS-02 on ISS (>May 2011,3y)

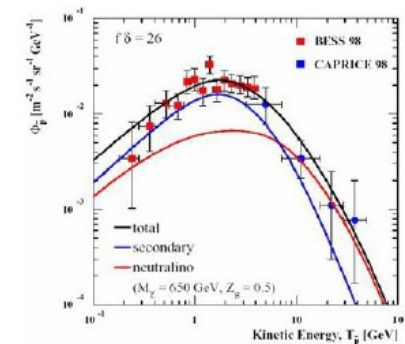
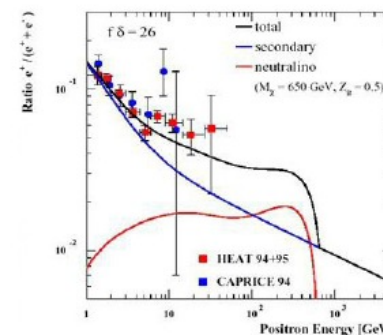
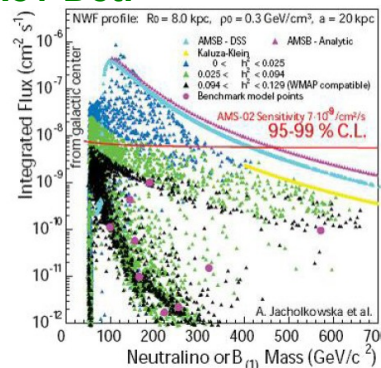
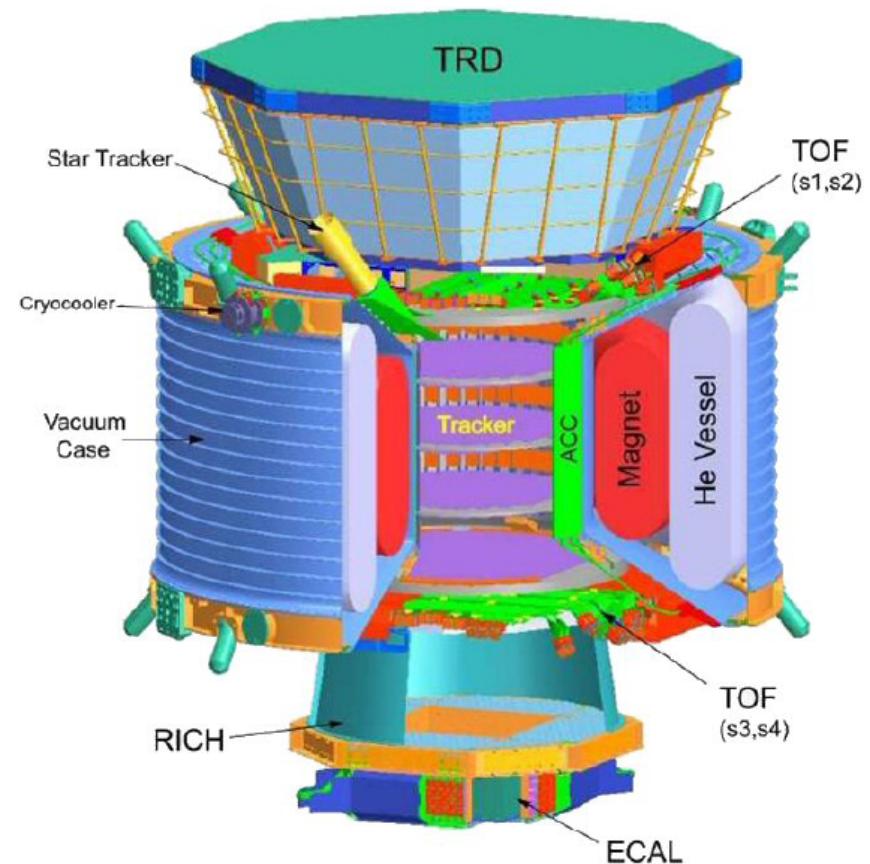
➡ AMS-01: Pioneering Experiment on Space Shuttle

### ➡ Main Components

- Permanent magnet → uniform magnetic field  $\sim 0.14$  Tesla over  $\sim 1\text{m}^3$
- Superconducting Magnet as Analyzer planned/abandoned
  - »  $0.8\text{T/m}^2$
  - » Rigidity up to  $3\text{TeV}$
  - » Nuclei Analysis up to  $12\text{GeV/n}$
- Transition Radiation Detector to Identify  $e^-$  versus Hadrons
- Ring Imaging Cerenkov Det. (aerogel/ $\text{NaF}_2$ )
- Time of Flight

### ➡ Goals

- Dark Matter?
- Antimatter?



# ACE/CRIS: Isotopes in Cosmic Rays



## ★ High-Resolution Mass Spectrometry

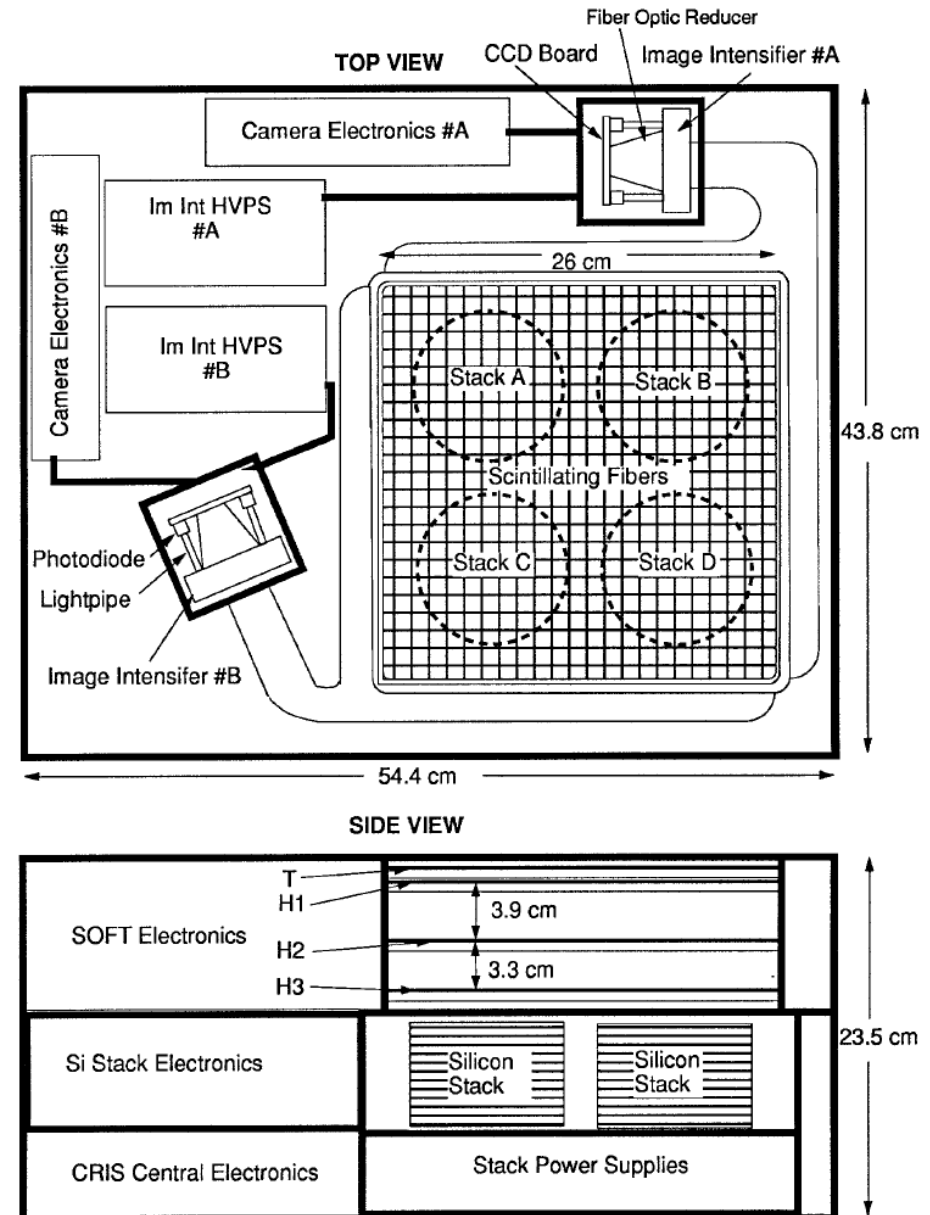
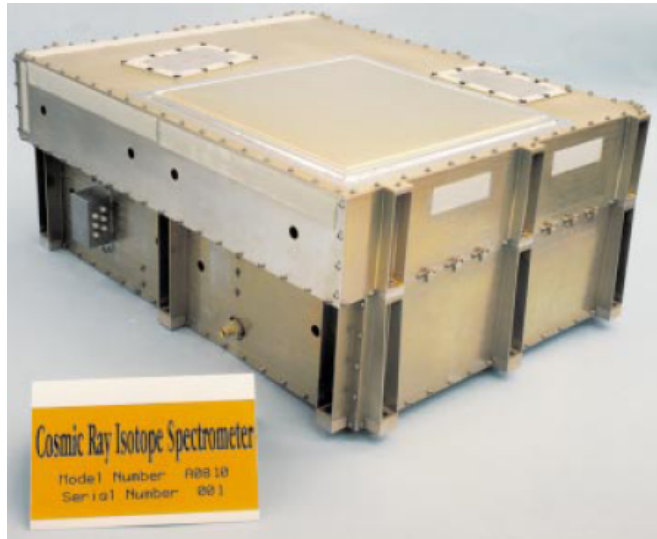


Figure 6. CRIS instrument cross section. The side view shows the fiber hodoscope which consists of three hodoscope planes (H1, H2, H3) and one trigger plane (T) which are located above the four stacks of silicon detectors. The top view shows the fiber readout which consists of two image intensified CCDs at either end of the fibers and the four stacks of silicon detectors.



# CR Nuclei: Combining Measurements

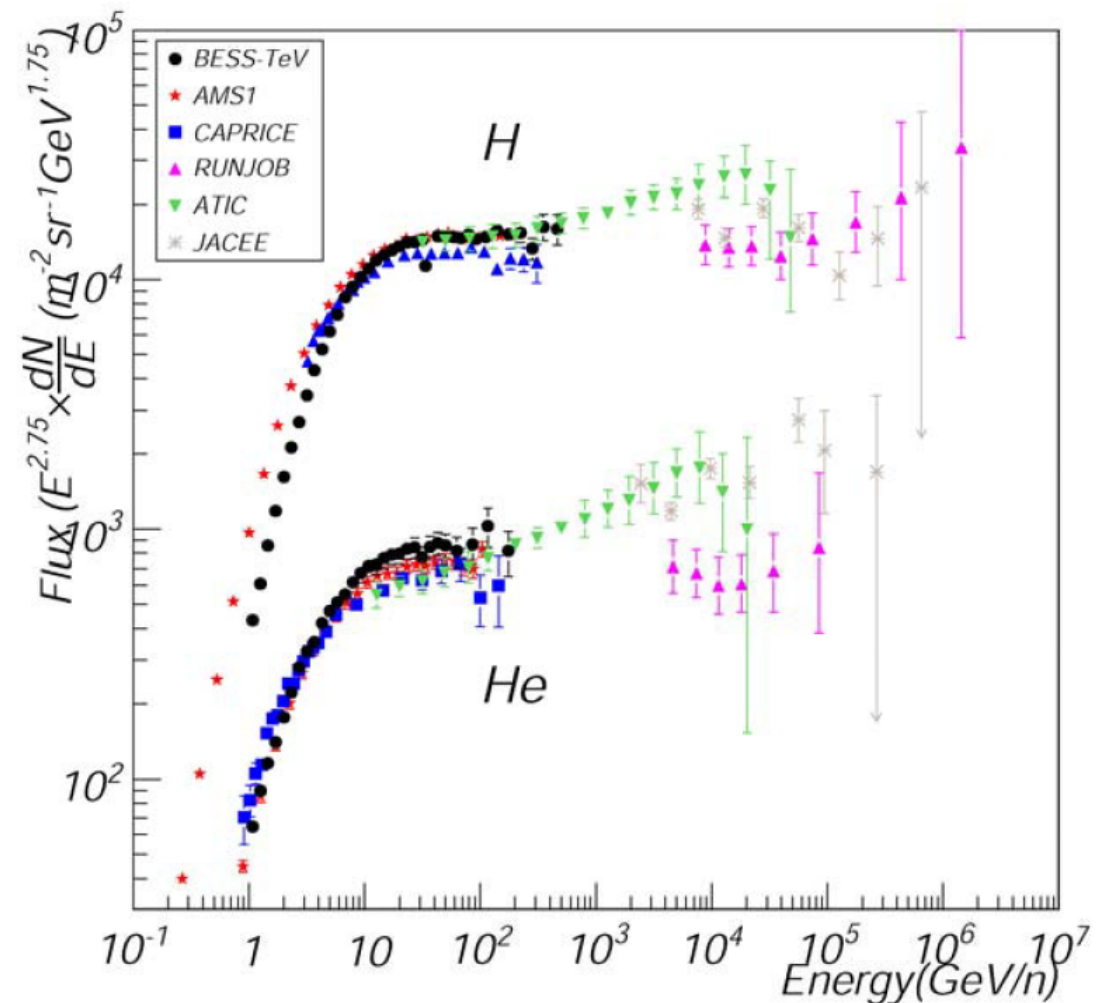


☆ H, He Spectra best-determined over larger E range

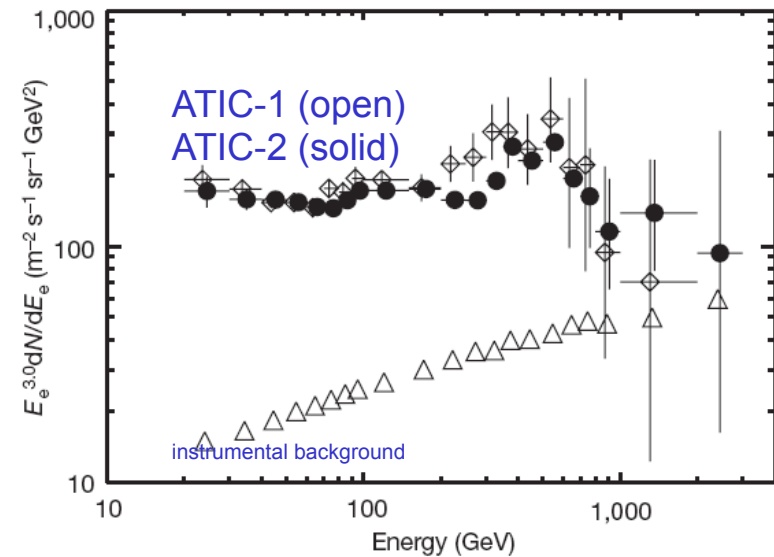
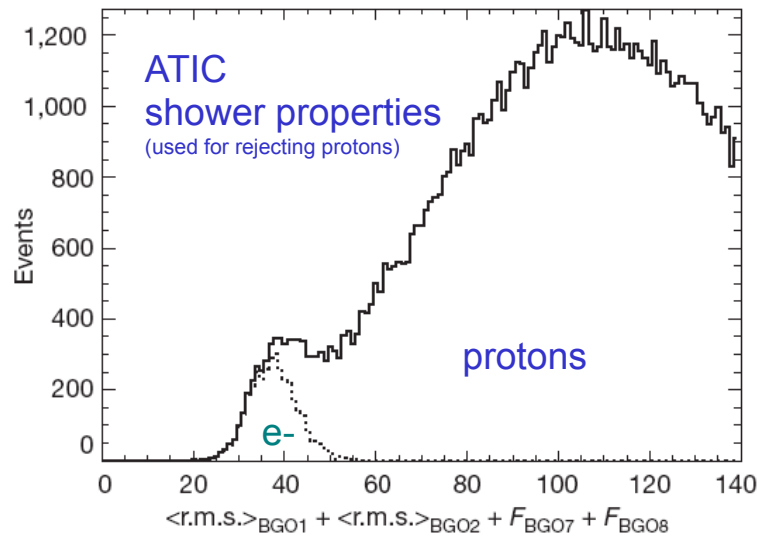
👉 direct mass spectrometers

👉 calorimeters

combined



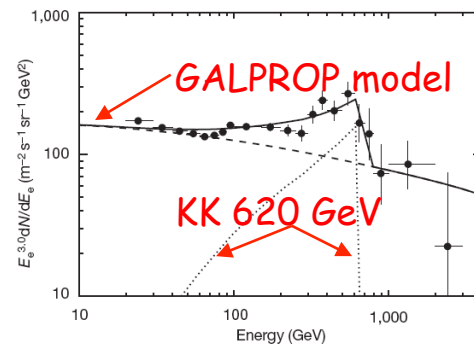
# Electron Results Consistent with Models?



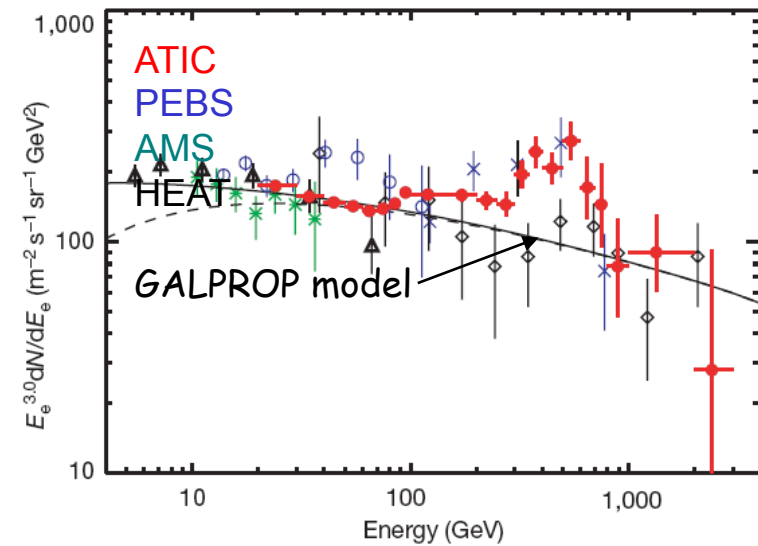
## ☆ Possible Excess at ~700 GeV

👉 Instrumental?

👉 Kaluza-Klein Dark-Matter Decay?



— Cheng et al., 2008



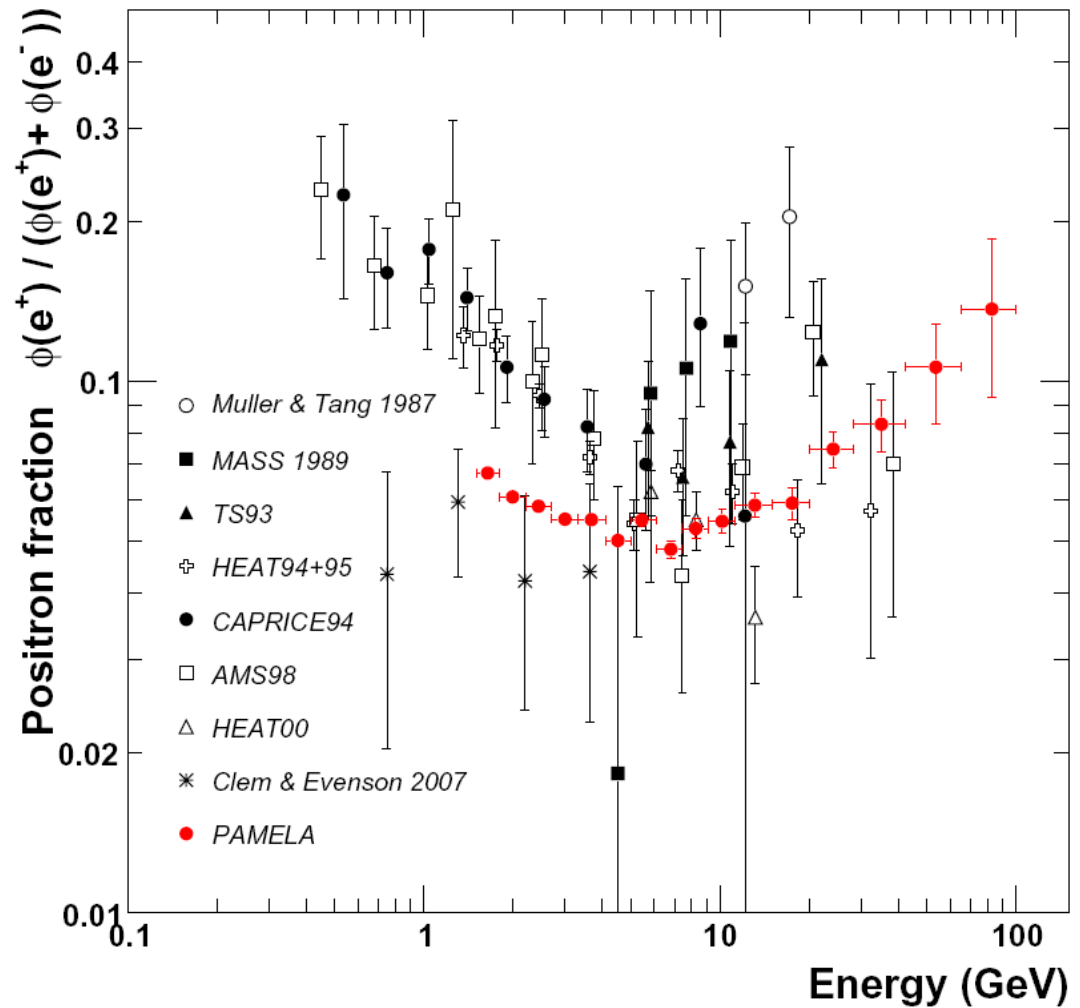
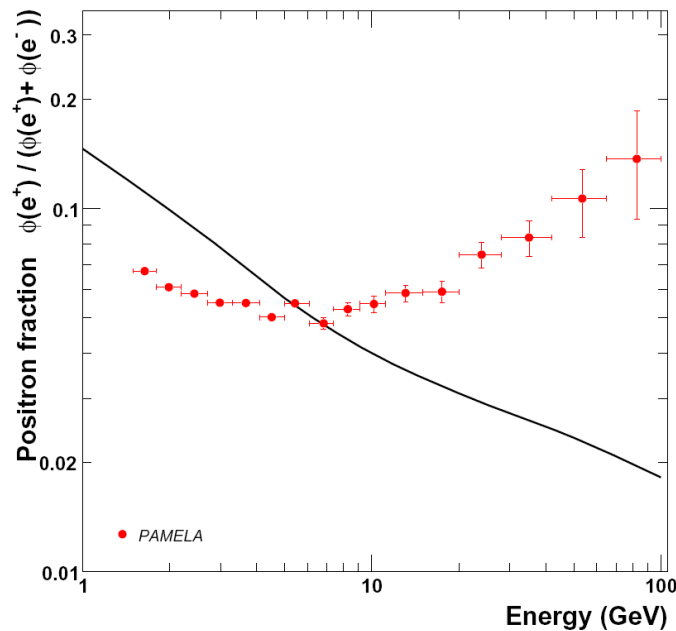
# Positrons in Cosmic Rays

★ Pair-Production in Hadronic Cascades → Generate  $e^-, e^+$

★ Results:

👉 recent: Pamela

👉 Inconsistent with Expectations from Propagation Model:



👉 Dark Matter Annihilations??

# Kascade Results:

Antoni et al. 2005



- "Knee" is observed to lie at  $\sim 5$  PeV
- Knee energy increases with particle mass
- ★ Analysis limited by systematics from hadronic interaction model for the upper atmosphere

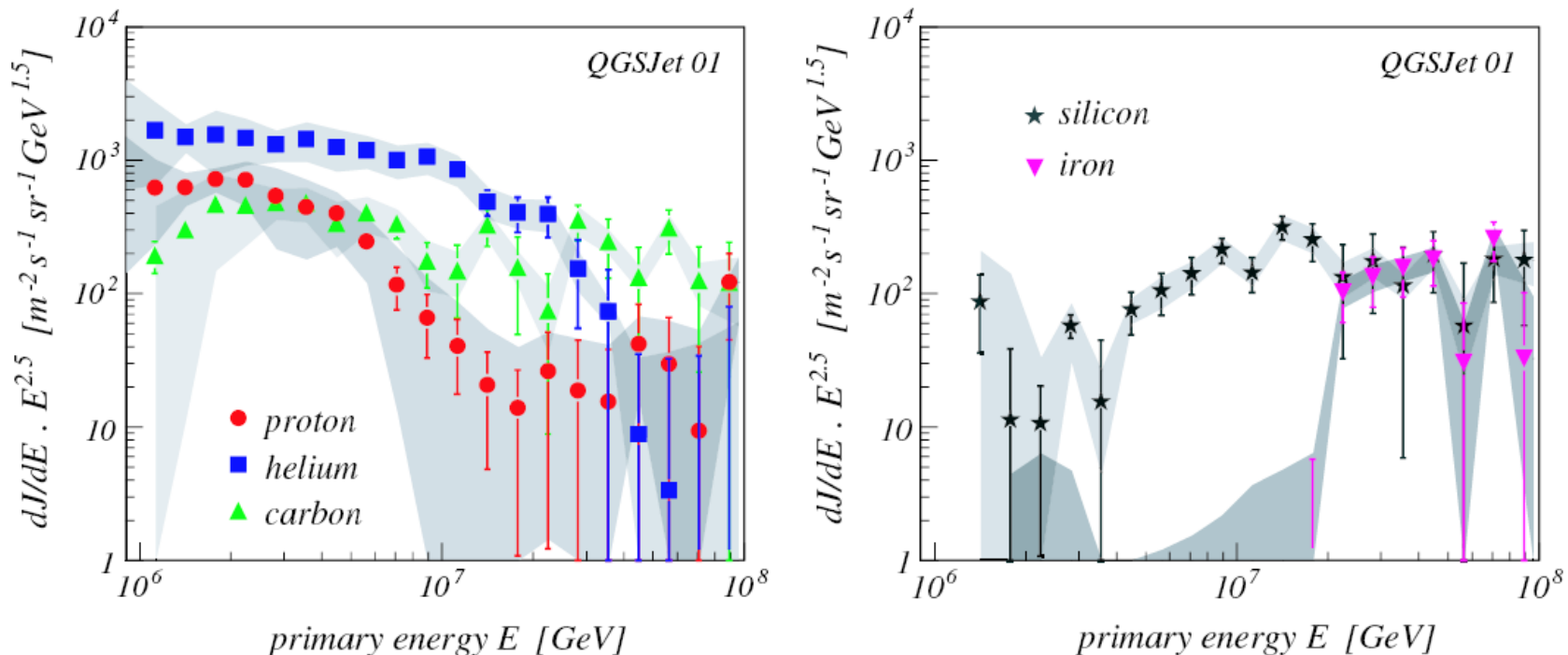


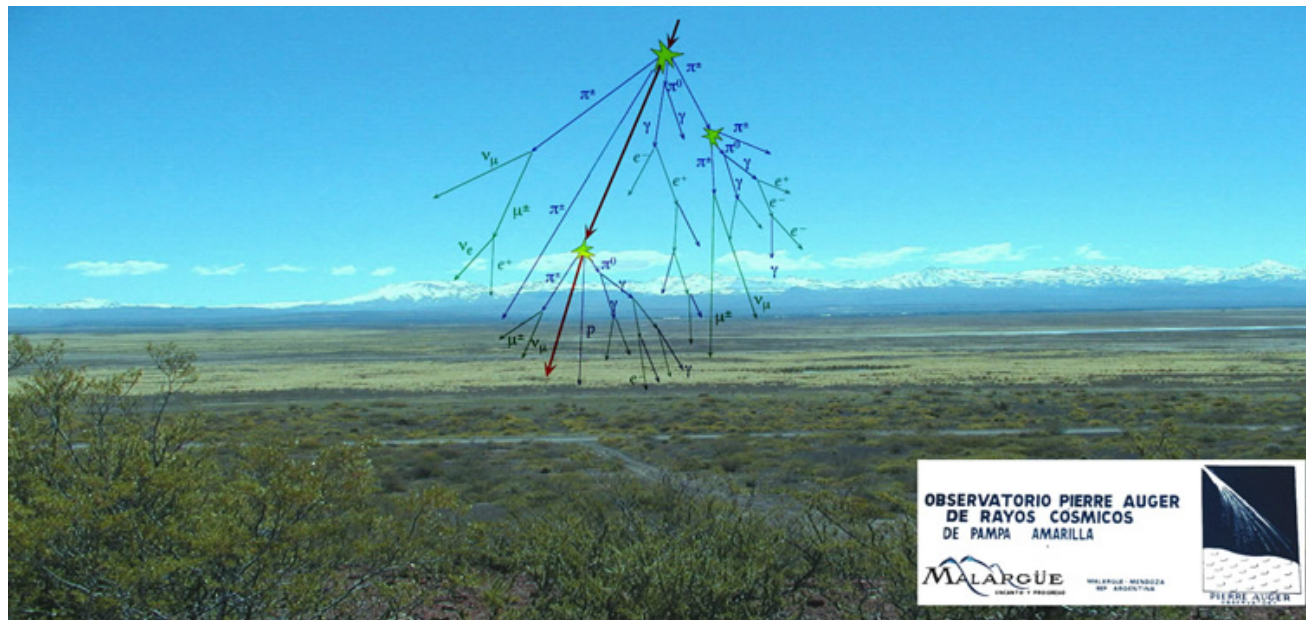
Fig. 14. Unfolded energy spectra for H, He, C (left panel) and Si, Fe (right panel) based on QGSJet simulations. The shaded bands are an estimate of the systematic uncertainties due to the used parameterizations and the applied unfolding method (Gold algorithm).

# The PIERRE AUGER Project

(First-time) Combination of

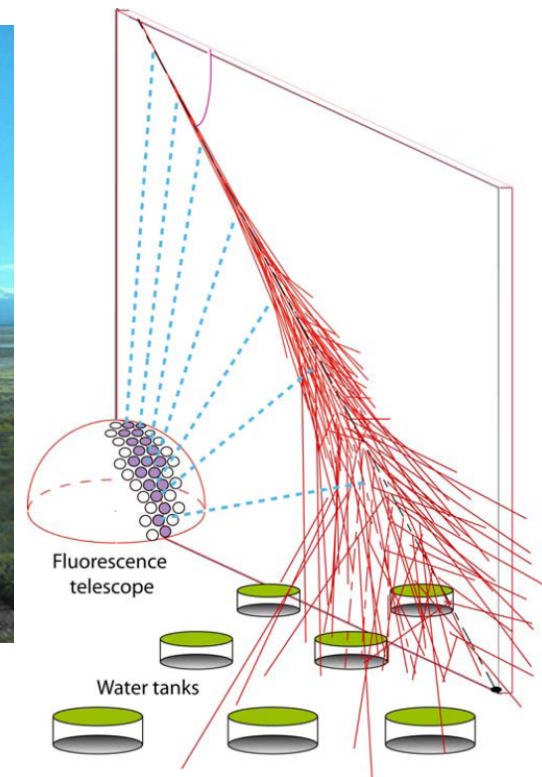
- particle detectors
- fluorescence light detectors

- reproduce complete evolution of shower
- determine direction, energy and type of the cosmic particles



Energy range: above  $10^{18}$  eV

- study of the highest energy particles

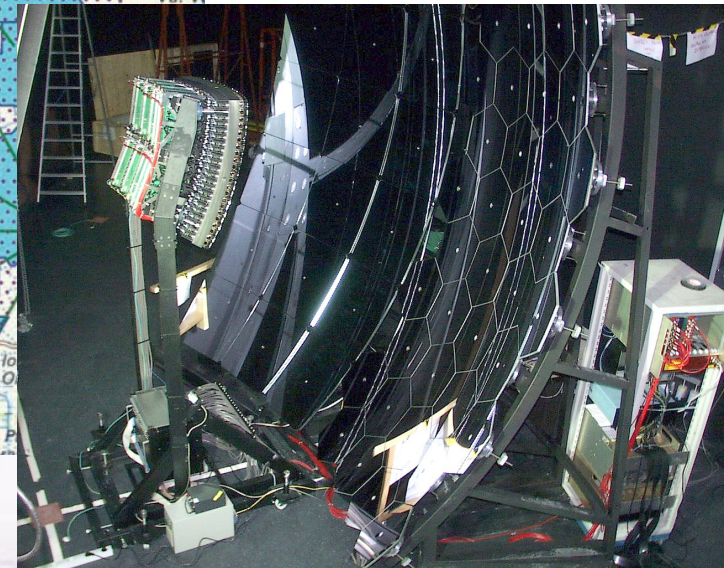
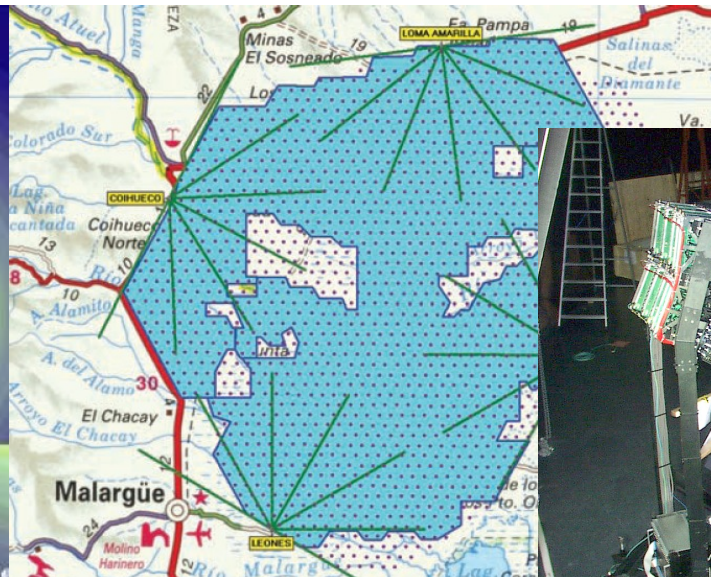
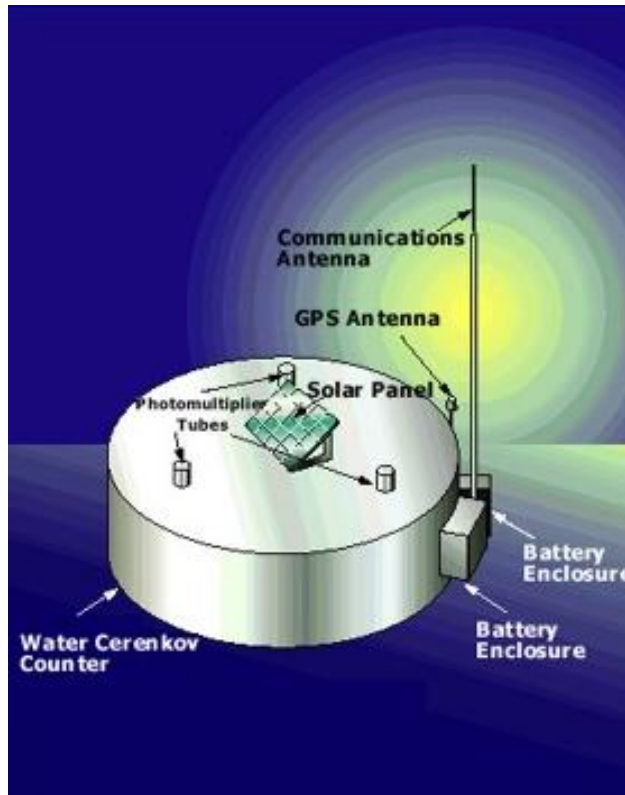




# PIERRE AUGER PROJECT – MENDOZA (ARGENTINIA)

1600 Water-Čerenkov-detectors,  
distributed over area of 3000 km<sup>2</sup>

One of 4 fluorescence light  
detectors (in total 30 telescopes)

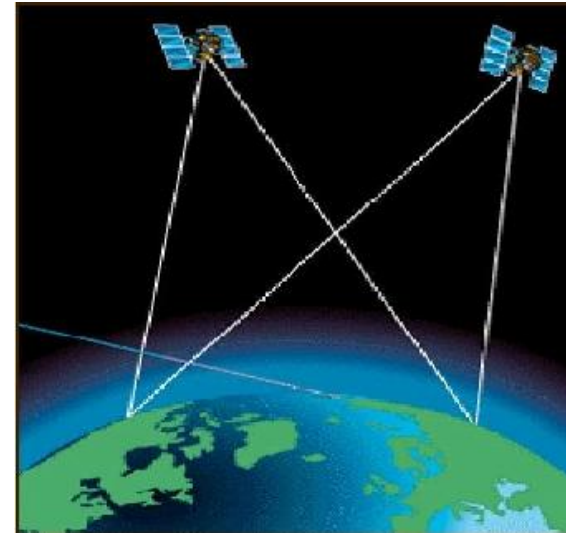


# Future (Bigger) Cosmic-Ray Shower Experiments

- OWL (Orbiting Wide-angle Light-collectors)

- Use of the (full) Earth atmosphere as detector
- Observation of the fluorescence light from two satellites

„in study phase“



- EUSO (Extrême Universe Space Observatory)

- also use of Earth atmosphere as detector
- Detector instrument(s) on the international space station ISS

„Phase A study“ – Goal: Launch 201x

# Neutrino Sources and Detectors



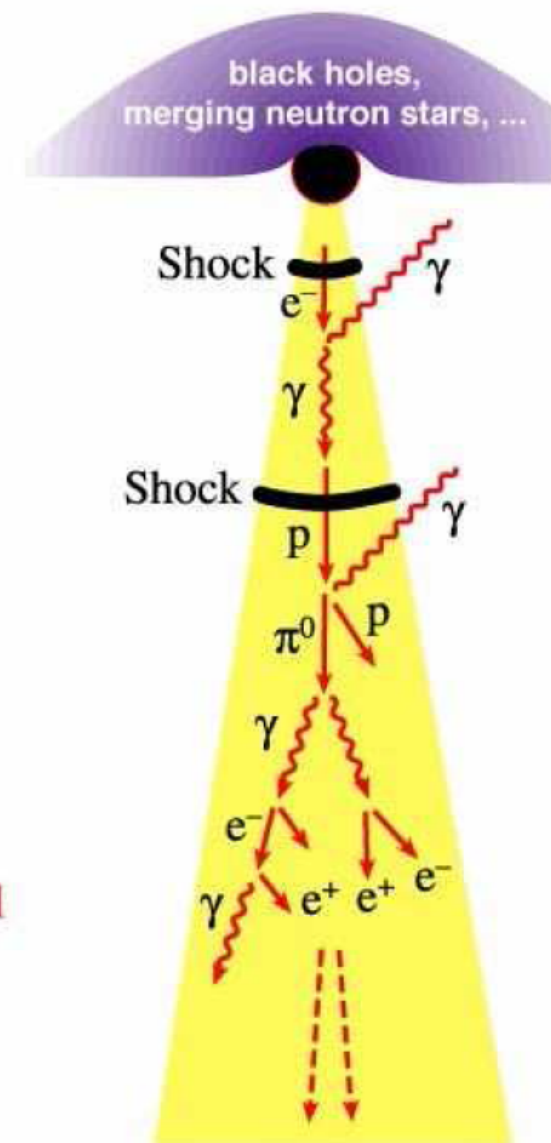
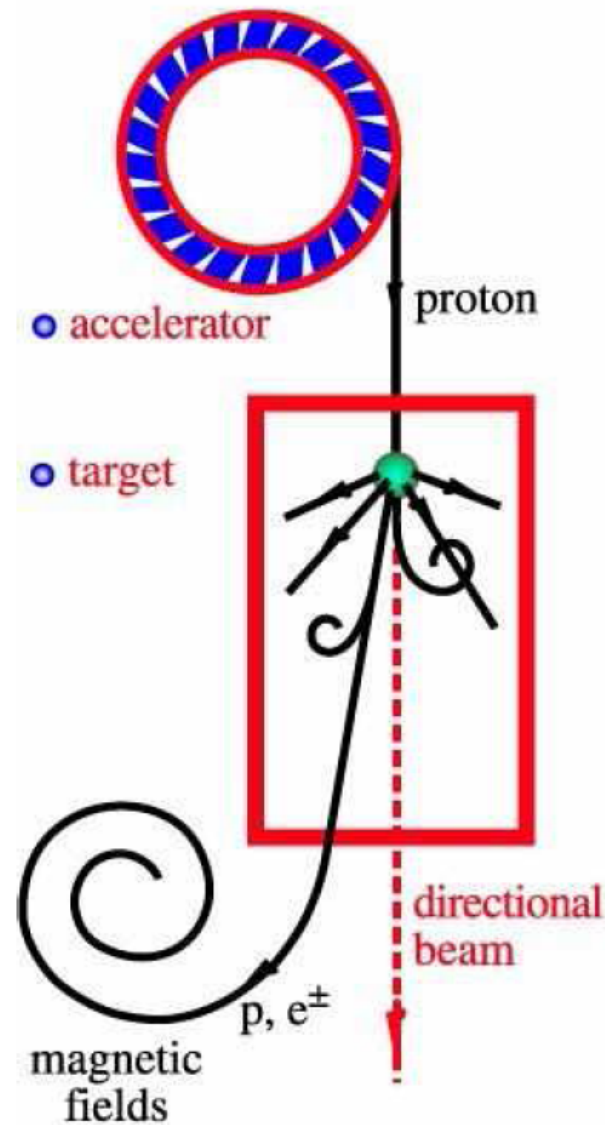
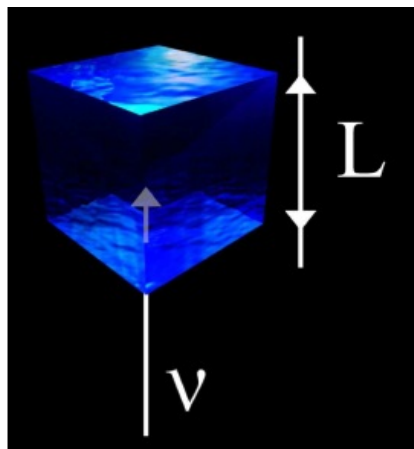
☆ **High-Energy Nucleon Beams are Neutrino Producers**

☆ **Cosmic Targets?**

☞ **Molecular Clouds in the Vicinity of Cosmic Ray Sources**

☆ **Detectors:**

☞ **Cerenkov Light in Water/Ice**

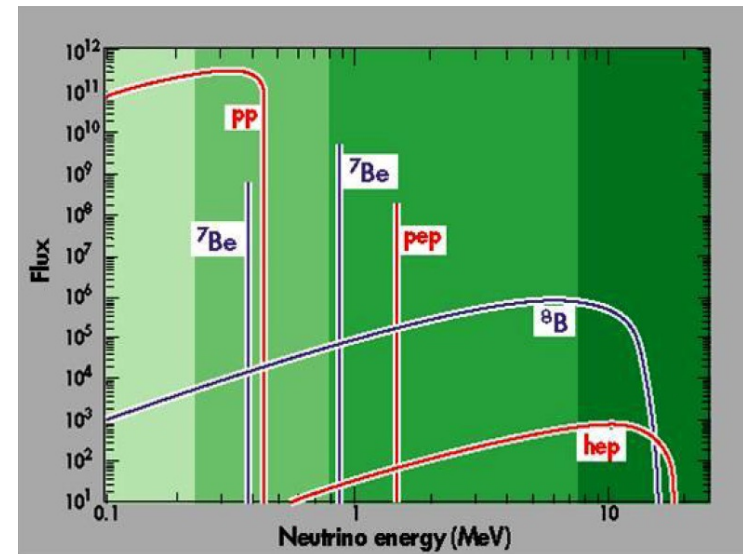




# More Sources of Neutrinos

## ★ Nuclear Fusion Reactions in Stars

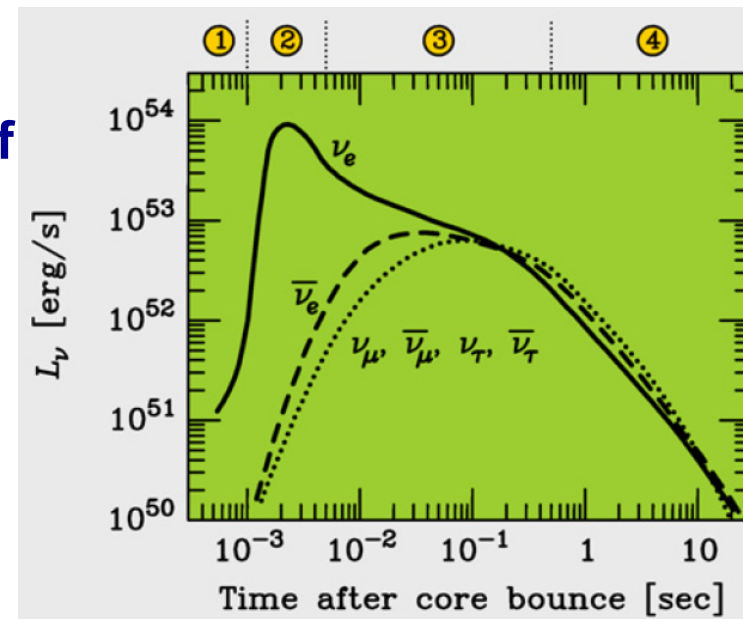
☞ Solar Neutrinos



## ★ Core-Collapse Formation of Neutron Star

☞ Neutronization

☞ Proto-Neutron Star  
Thermal Emission



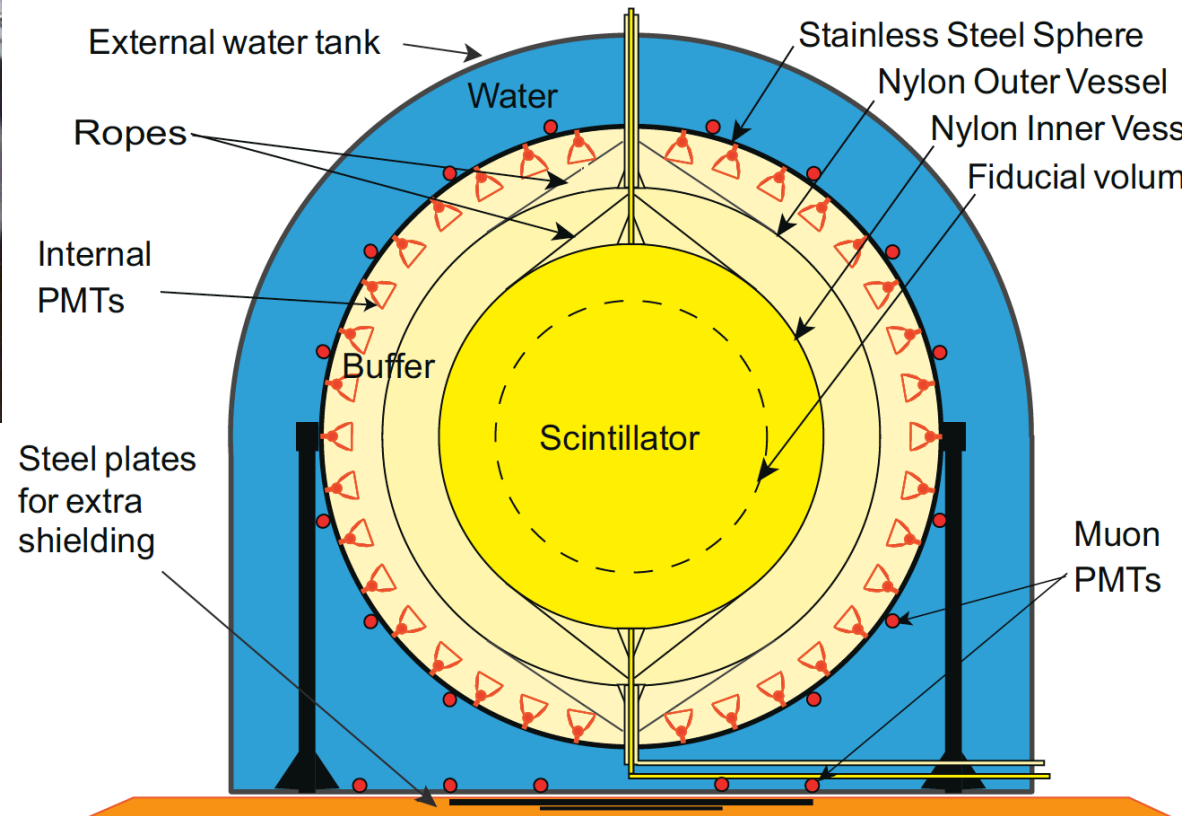
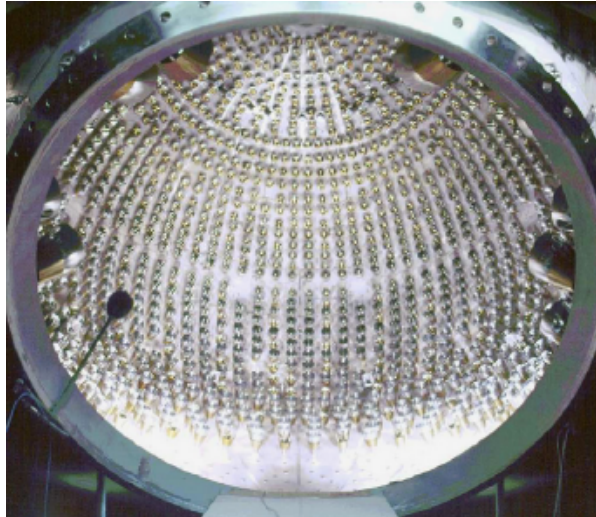
# Borexino



- Scintillation Detector in Gran Sasso Lab. (Italy)

operated since May 2007

## Borexino Detector



### ★ Principle:

search for events without external trigger, creating recoil e-, protons, or C nucle. (detect scintillation)

suppress very efficiently other background

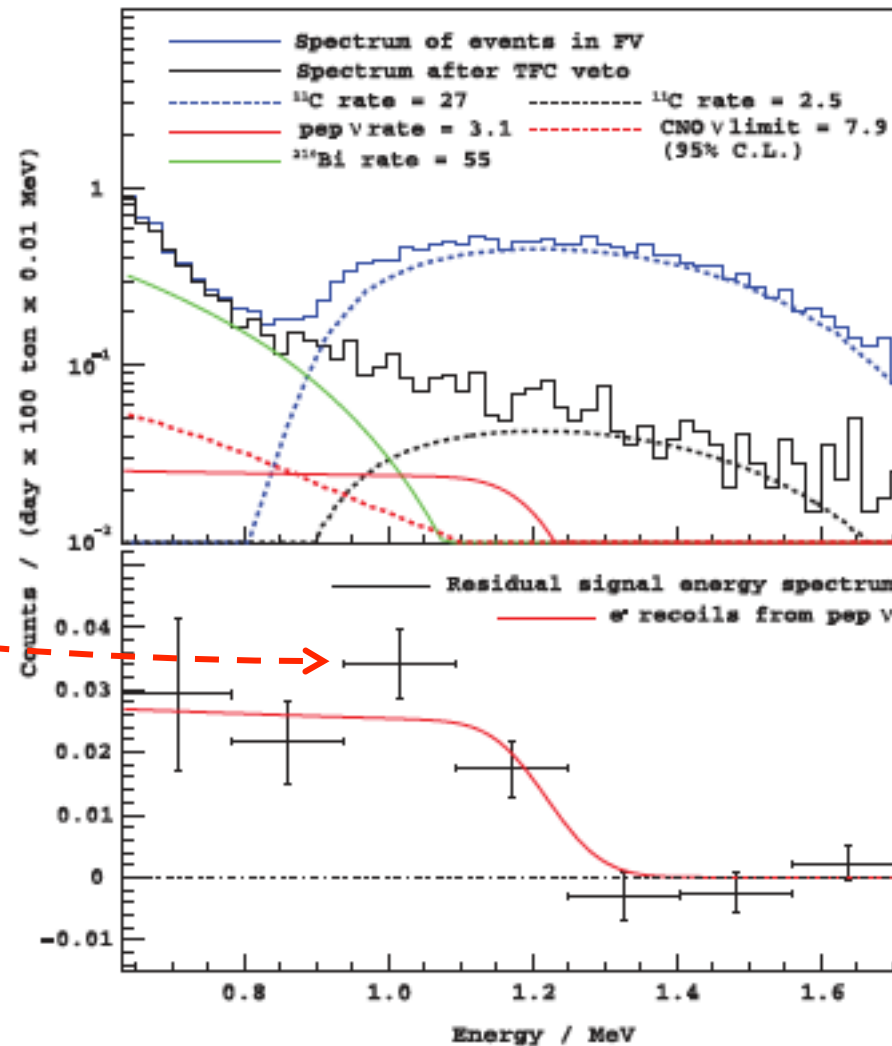
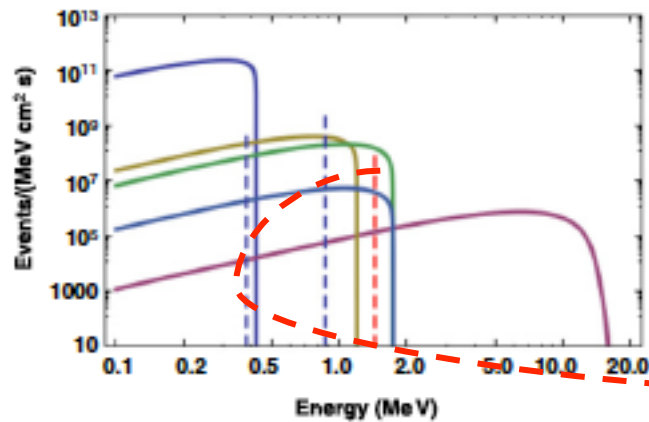


# Borexino Results



- First-ever Detection of Neutrinos from pep Channel of Solar H Burning

👉 Bellini et al. 2012



# Detection of High-Energy Cosmic n's

## ★ High-Energy Interactions

→ **Secondaries**

→ **Cerenkov Radiation**

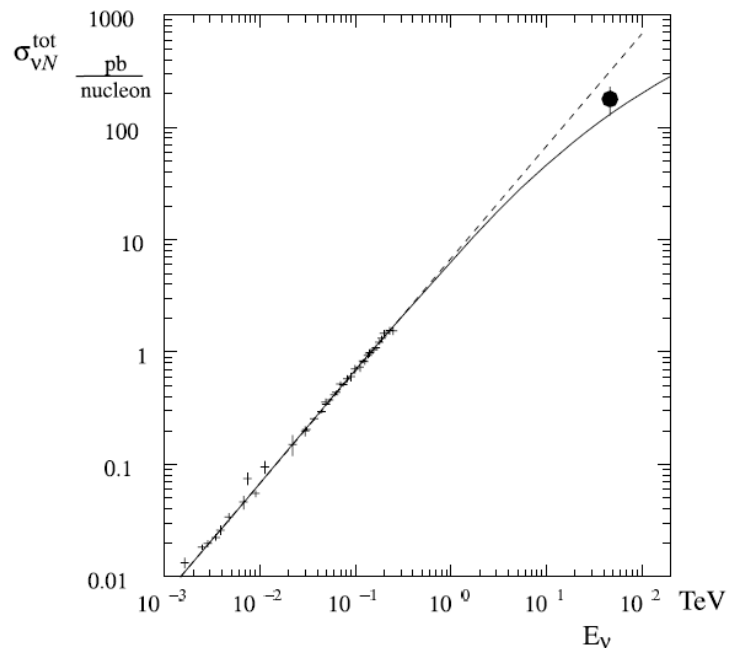
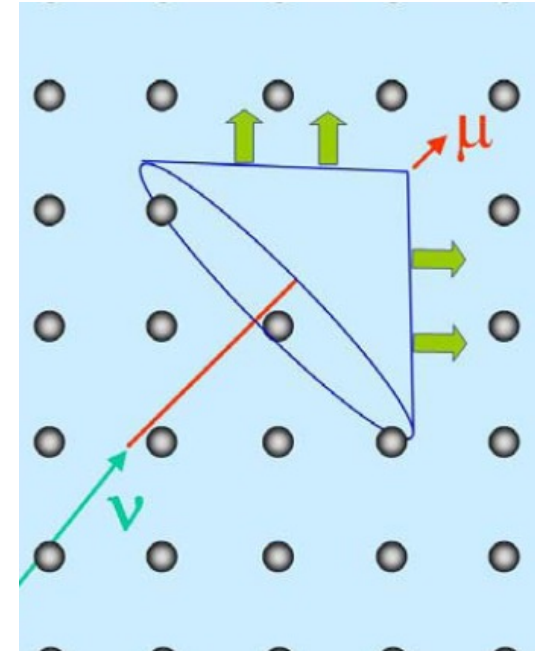
## ★ Search for Cerenkov Flashes from Below in Large Volumes of Clear Water / Ice

→ **BAIKAL (1993+)**

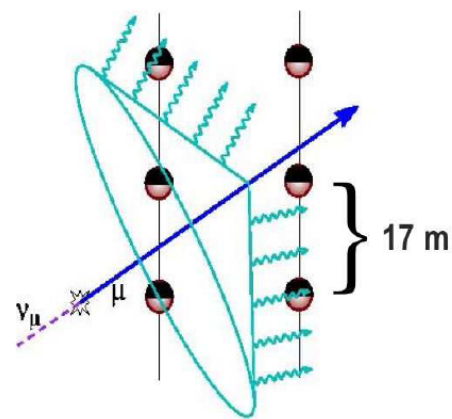
→ **AMANDA, IceCube: Antarctica (2000+)**

→ **ANTARES: Mediterranean Sea (2007+)**

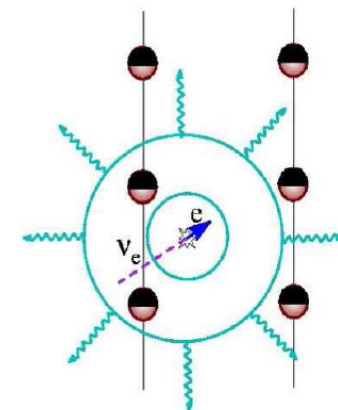
→ **NESTOR, NEMO**



~ km-long muon tracks from  $\nu_\mu$



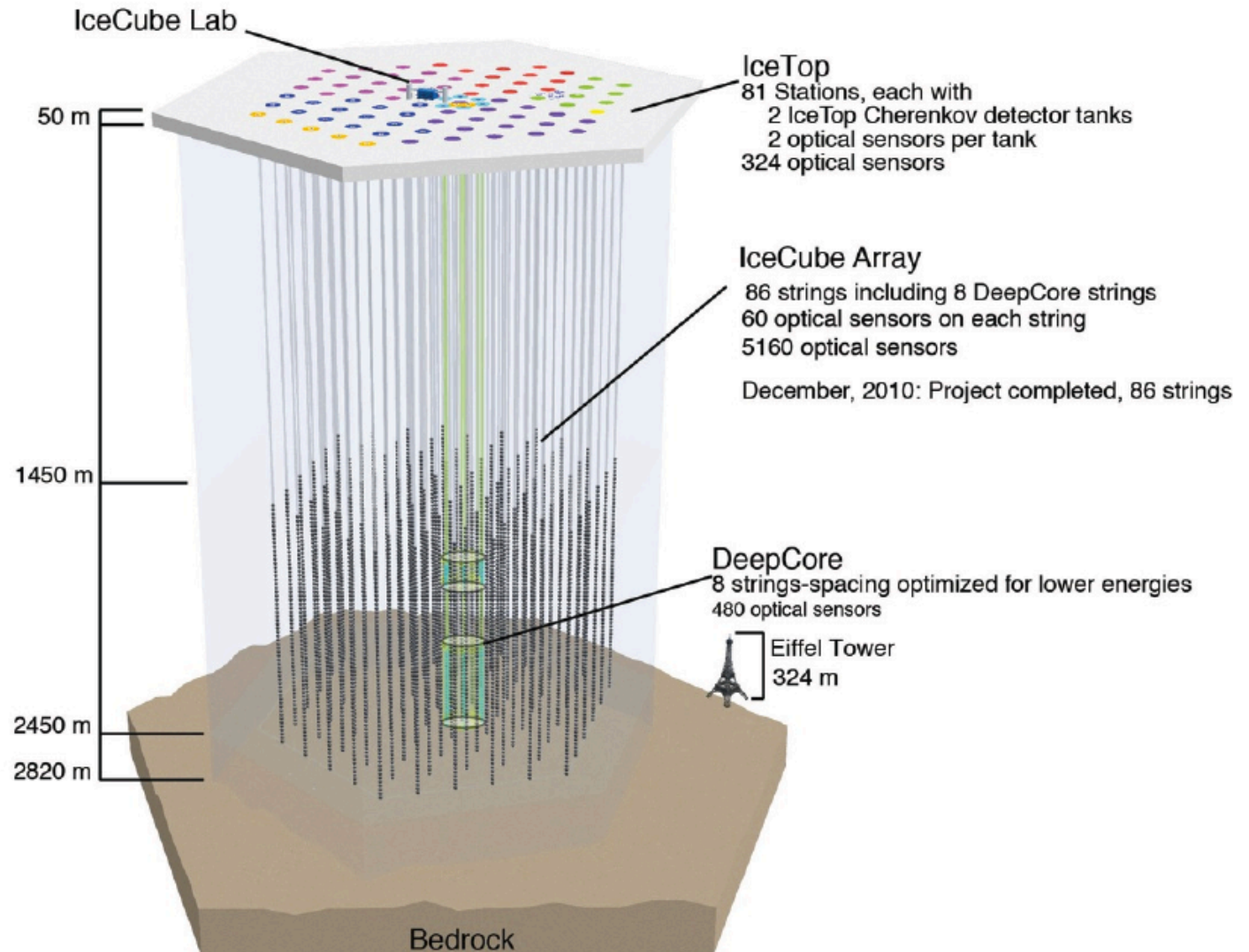
~10m-long cascades from  $\nu_e, \nu_\tau$



# IceCube in Antarctica

## ★ Detecting High-Energy Neutrinos

👉 IceCube Completion Dec. 2010; partial-system data taken since 2005

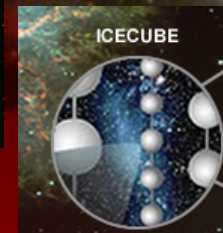
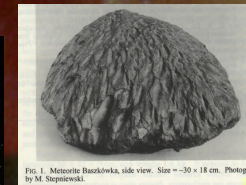
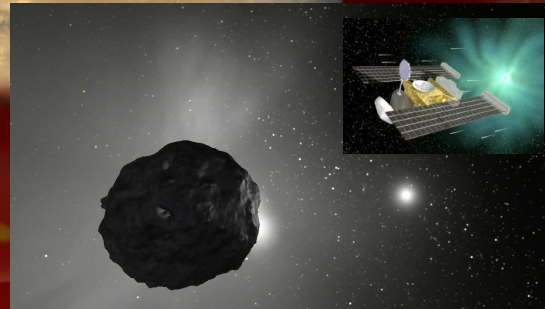




# Messengers from Cosmic Objects & Processes

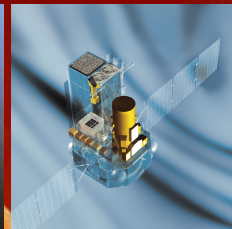
- **Material Samples**

- ☆ Meteorites
- ☆ Cosmic Rays
- ☆ Neutrinos



- **Electromagnetic Radiation**

- ☆ Radio / sum-mm / IR / optical / UV / X-rays / Gamma-Rays



- **others**

- ☆ Gravitational Waves

